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Employment, Education, and the Workplace

Volume II—Working Papers

Part A: Case Studies on the Introduction of Programmable Automation in Manufacturing: Work Environment Effects

Part B: Final Report: Education and Training Case Study Series

This is an OTA Working Paper that has neither been reviewed nor approved by the Technology Assessment Board

June 1984

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
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Volume II—Working Papers

Part A: Case Studies on the Introduction of Programmable Automation in Manufacturing: Work Environment Effects

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This is an OTA Working Paper used in the preparation of OTA's final report on Computerized Manufacturing Automation. The findings and conclusions of this report are those of the author and do not necessarily represent the views of OTA or the Technology Assessment Board. This report has not been reviewed or approved by the Technology Assessment Board.

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PREFACE

This volume contains papers written for OTA to assist in preparation of the report Computerized Manufacturing Automation: Employment, Education, and the Workplace. OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

1-C

INTRODUCTION

In April 1984, OTA published the final report of the assessment entitled Computerized Manufacturing Automation: Employment, Education, and the Workplace. The study was requested by the Joint Economic Committee; the Senate Committee on Labor and Human Resources; the Senate Committee on Commerce, Science and Transportation; and the Labor Standards Subcommittee of the House Committee on Education and Labor. It also received the endorsement of the House Committee on Science and Technology.

The OTA assessment focused on the use of computerized manufacturing automation in discrete manufacturing, particularly in metalworking industries such as transportation equipment and electrical and nonelectrical machinery. It examined the technical features of advanced manufacturing technologies, as well as their economic and social ramifications.

As a central part of the methodology for the assessment, OTA conducted in-depth case studies to describe and document some of the changes that are occurring in the work environment and in education, training, and retraining requirements as a result of the use of programmable automation in U.S. manufacturing facilities. The case studies represent one source of background material for the analyses that appear principally in chapters 4 and 6 of the OTA report (OTA-CIT-235, April 1984).

This volume contains four case studies on the effects of PA on the work environment. It also contains a cross-analysis of fourteen case studies that describe instructional programs offered by a variety of public and private organizations to develop skills currently associated with programmable automation. Copies of the individual case studies on instructional programs are available from the OTA Publishing Office (202) 224-8996.

In view of the lack of reliable information concerning the effects of programmable automation on the work environment and instructional requirements, OTA chose the on-site case study as an effective method of data collection. The case study was also considered an appropriate mechanism for describing some of the important issues that are emerging within individual work sites where programmable automation has been introduced. Researchers who spend an extended period of time in an organization interacting with the work force and with management derive a sense of what programmable automation means to the people who are most closely involved with its introduction and use.

The case study results provide valuable insights for those interested in the possible effects of programmable automation on the work force and on the U.S. instructional system. While the case study findings are limited to the sites visited and cannot be used to generalize about overall conditions, they identify experiences and problems that may be common to many organizations.

Case Studies of Work Environment

The work environment case studies were conducted during April through June, 1983, by researchers from the Massachusetts Institute of Technology's (MIT) Program in Science, Technology, and Society. The principal investigator was Harley Shaiken; he was assisted by Sarah Kuhn and Steve Herzenberg. An interdisciplinary group of individuals at MIT, including engineers and social scientists, participated in a seminar series to discuss the findings and conclusions of the case studies. They also provided criticisms, commentary, and advice to both the MIT team and OTA.

The case studies attempted to identify qualitatively some of the ways in which programmable automation is currently affecting the work environment in selected sites; quantitative analysis was not feasible given the small number and the diversity of observations. Four case studies were conducted - one each in the agricultural implements, aircraft, and automobile industries, and one encompassing a group of seven small metalworking shops. The three large companies studied were selected out of a list of approximately 20 firms that was compiled in consultation with a number of leading trade associations. The small metalworking shops were chosen after discussions with knowledgeable individuals and organizations in New England, the geographic region selected. While the companies are all advanced users of programmable automation, they differ in several important respects, including company size, product batch size, union representation, financial health, current level of market demand,and geography.

The case studies are based on 3- to 8-day visits by two researchers to the three large companies, and 1-day visits to each of the seven small machine shops. Six technologies were studied - numerically controlled machining (NC), flexible manufacturing systems, management information systems, automated materials handling, robots, and computer-aided design. NC machine tools receive particular attention in the case studies because they are among the oldest modern examples of the application of digital technology to manufacturing, dating from the early 1950's. As such, NC represents the backbone of computerized production equipment, and it is the most important application to date of computers in small and medium batch machining.

Education and Training Case Studies

The introduction of programmable automation has already generated changes in requirements for education, training, and retraining. OTA found that there is every indication that as use of advanced manufacturing technologies becomes widespread, additional changes in short-term and long-range instructional requirements will result. In order to examine this phenomenon, a central task in the OTA study involved analyzing the potential impact of programmable automation on the U.S. instructional system. OTA measured effects on the supply of technical and engineering instructors, on existing instructional facilities, on equipment requirements, and on curriculum content. In conjunction with this segment of the study, 14 in-depth, on-site case studies encompassing 20 programs were developed by Jeanne Argoff, Ph.D., principal investigator. The objective was to highlight instructional programs that are representative of relatively successful efforts that have been initiated by secondary and postsecondary educational institutions, vendors of programmable equipment and systems, users of programmable automation, labor unions, and Federal and/or State-funded retraining facilities. The cross-analysis of instructional programs included in this volume is derived from an examination of the 20 programs that were the subjects of case study investigation.

The research associated with case study development took place during the period July 1982 to June 1983. The initial objective of the research project was to identify and contact a selected sample of institutions, organizations, and agencies known to offer or having the potential to offer programs designed to prepare individuals for jobs in computer-automated manufacturing environments. Approximately 300 individuals representing industry, educational institutions, government agencies, professional associations, training and/or education associations, technical societies, and community organizations were contacted at this stage. The process of identifying potential case study sites was augmented by a literature search. A sample of 100 training or education programs was identified, from which 20 were chosen to be the subjects of 14 case studies. Programs were chosen from all four quadrants of the country, with a concentration of four programs from the heavily industrialized areas of southwestern Michigan. For a more complete description of the case study methodology, see Appendix A of the OTA assessment report.

Acknowledgments

OTA wishes to acknowledge with thanks the cooperation and contributions of the companies and individuals who participated in the case studies and those who were advisors and reviewers. Each case study was subjected to a thorough review by employee and management representatives interviewed at each site in order to ensure that all data and information contained in each case description were accurate and consistent with actual conditions. Some of the firms requested that they not be identified by name, and this wish has been respected. In the work environment case studies, this request was made by one of the participants; for the sake of conformity, none of the work environment case study sites has been identified by name.

AUTOMATION AND THE WORKPLACE:

Case Studies on the Introduction of Programmable Automation in Manufacturing

Prepared for the Office of Technology Assessment

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July 1983

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The authors would like to express their gratitude to Sean Doyle, whose informed and enthusiastic help has significantly improved this study. Shawn Finnegan, Hugh Gabrielson, Nathaniel Kuhn, Susan Newell, Carol Scanlon and Larry Snyder all gave generously of their time and provided crucial assistance. The participants in the series of seminars at which the authors presented and discussed their findings made many useful observations and suggestions that have substantially improved the analysis contained in the case studies and the summary. Finally, none of this research would have been possible without the active and unstinting participation of the companies, trade unions, workers, and managers who contributed their time and insights. The views expressed in this study are those of the authors, except where otherwise noted, and do not necessarily reflect the views of the project's consultants, assistants, or interviewees.

AUTOMATION AND THE WORKPLACE:

Case Studies on the Introduction of Programmable Automation in Manufacturing

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SUMMARY

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Table 1. Characteristics of Small Metalworking Shops Studied by OTA

SUMMARY

I. INTRODUCTION

Faced with intensely competitive market conditions, U.S. companies are turning to programmable automation to enhance the productivity and increase the flexibility of their manufacturing operations. The usefulness and versatility of computerized technology is such that it has found multiple applications in virtually every industry in the country. This report summarizes the findings of four case studies investigating the impact that these new programmable technologies are having on the work environment in manufacturing settings. The case studies are based on investigations of three major manufacturing firms -- one in the automobile industry, one in the aircraft industry, and one in the agricultural implements industry -- and a group of seven small metalworking job shops. All of the companies studied share one important characteristic: they are leading users of programmable automation in their industries.

As a result of the extraordinary flexibility of computer technology, the application of computers to the workplace offers a range of options for organizing work.[1] While the design of a machine or system sets the stage for its work environment effects, the specific circumstances in which the technology is introduced also play a crucial role in shaping the environment in the automated workplace. The impact that a programmable system will have in practice is influenced by the managerial goals of the company introducing the technology, the type of technology already employed, the new system's actual shop floor performance, the way in which work is organized, the character of labor-management relations, and the attitudes of workers using the system. These features of the context determine, together with the technical capabilities of the new system, what the effect of computerized automation on the work environment will be.

The companies studied gave different reasons for adopting programmable automation. All agreed, however, that it was vital for their competitive success. Some of the technical and economic benefits cited included greater flexibility to make design changes and to retool quickly from one product to another; higher quality as a result of the repeatability and accuracy of the technology; a new capability to produce products that would have been difficult or impossible with conventional methods; and lower labor costs because fewer workers are needed for a given amount of work.

At every company studied there was a common organizational theme: establishing more effective managerial control over the activities of the enterprise. In the firms that produced parts in small and medium batch sizes -- the small metalworking shops, the agricultural implement producer, and the aircraft company -- programmable automation was the centerpiece of a strategy to establish a more managerially-directed flow of parts through production, in some cases approximating the even flow of continuous-process industries. At the automaker, where the mass production of parts has been carried out for years on a moving assembly line, the company sought to extend this flow to the remaining off-line areas of the welding operation. The aircraft company also sought to streamline the flow of information through design and engineering and, in the process, to move decision making to as early a point in the design and manufacture of the airplane as possible. An important corollary of these changes was minimizing human input. This extension of control in design and production, in management's view, makes possible a better coordination and a more efficient use of the firm's resources. These organizational choices, however, have important consequences for the work environment.

Because of the great variety of technologies that use computers as their base, and because of the wide variations among companies in terms of the context into which these technologies are placed, there is no single impact of programmable automation on the work environment. Instead, there are some overall themes that emerge from the four case studies, each of which may hold true in varying degrees for the companies studied. This summary attempts to describe these themes and to indicate in what way they were evident in the work environments of the companies that were the subject of the research. The major themes are as follows:

> Increased Interdependence: The introduction of programmable technologies brought about a greater interdependence among production workers, greater collaboration among maintenance workers, and the necessity for increased cooperation between production and maintenance workers.
>
> Decreased Autonomy: Computer-based automation is used in a way that results in decreased autonomy for workers, stemming from the removal of production decisions from the shop floor, the electronic monitoring of some work areas, and the attempt on the part of management to establish an even flow of parts through the plant and of information through the company.
>
> Changes in Skill Requirements and Occupational Structure: There was a tendency to embody skill in machines or to move skill to an earlier point in the design and manufacturing process. In occupations such as highly skilled machining this meant that fewer skills would be required on the job. Maintenance work, however, tended to require more skills.
>
> Boredom: One of the consequences of systems intended to minimize operator intervention is that machines may run for longer, although not indefinite, periods of time without active intervention by the operator. For some machine operators, boredom on the job has become a widespread complaint. Some maintenance tasks, however, have become more challenging.
>
> Stress: The pressure on many production workers, maintenance workers, and supervisors -- the consequence of working on complex, very expensive, highly integrated systems -- combined with the lack of autonomy creates stressful conditions in the workplace.
>
> System Downtime: Because of the complexity of programmable systems and their high level of integration, the effects of problems with any unreliable element of the system tend to spread, affecting the work pace of production workers and putting great pressure on those involved in the maintenance of the system. Downtime may decrease with better system design and more reliable components.
>
> Safety: Some applications of programmable technology make the workplace safer, either by eliminating hazardous jobs altogether or by allowing the operator to stand further from the machine during operation. Others may make the workplace more

dangerous because more machinery is introduced into a given work area and production and maintenance workers find the operation of these systems somewhat unpredictable.

Cleaner and Lighter Physical Work for Operators: Some forms of programmable automation have reduced or eliminated heavy or dirty work. In some cases, new jobs requiring physical labor are created in the place of the old, heavier jobs.

Training: Operators and maintenance workers frequently expressed a strong desire for more training that would allow them more effectively to run or to repair the machines to which they were assigned.

Displacement: The combination of substantial layoffs at all the large companies and the widespread perception among workers that the introduction of computerized automation caused significant displacement raised strong apprehensions among workers about their future job security.

As the findings described above suggest, the implementation of programmable automation, in the context of the firm's move toward the creation of a managerially-directed flow of production, did not improve the quality of the work environment in the firms studied. While some jobs become more challenging or less physically taxing, the overall effect for many occupations is a less desirable working environment.

II. SCOPE OF THE STUDY

The study looks at six technologies in four industries. Collectively these technologies span an important range of applications at the core of manufacturing. The technologies are numerical control (NC), flexible manufacturing systems (FMS), management information systems (MIS), materials handling, robots, and computer-aided design (CAD). These technologies, selected from numerous examples of programmable automation, are particularly important for a variety of reasons. Numerical Control (NC) is the most important application of computers in small and medium batch machining and is also among the earliest uses of computers in metalworking. Flexible manufacturing (FMS) integrates numerical control into a larger computer controlled system that is the prototype of the automatic factory. Management information systems (MIS) collect, transmit, and process data in a way that provides more comprehensive and immediate information to management about operations in both batch and mass production industries. Robots are a versatile technology that can be used in a wide range of production settings either as a stand-alone machine or as part of a larger system. Finally, computer-aided design (CAD) exemplifies the use of computers to transform the design process and the organization of production.

While these technologies are all computer-based, their effects on the work environment differ from each other in substantial ways. Numerical control receives particular attention in this study because, although other programmable technologies may monitor the activities of workers or replace the worker entirely, numerically controlled machine tools continue to require the presence of an operator, while significantly changing the character of the person-machine interaction. The changes in the NC operator's job have implications for other situations in which there is a direct interaction between person and machine.

The three large companies studied were selected out of a list of approximately thirty firms that was compiled by the research group after consultation with a number of leading trade associations. The small metal working shops were selected after discussions with knowledgeable individuals and organizations in New England, the geographic region selected. All the companies chosen are advanced users of programmable automation but differ from each other in several important respects, including: batch size, company size, union representation, financial health of the company, current level of market demand, and geography.

- batch size: the number of units produced ranged from hundreds of thousands of cars in the auto assembly plant to one-of-a-kind parts in a small prototype metalworking shop. In between, the aircraft and agricultural implements companies represented medium batch production. Production in small and medium batch industries has been very resistant to automation in the past because of the variability and complexity of the work. The cases in this study show the power of programmable technology for small batch producers as well as its ability to bring increased flexibility to mass production.

- company size: the metalworking job shops in this study employed from 10 to 200 people, with sales ranging from $300,000 to $25 million per year. The three larger companies employed from 40,000 to 80,000 people, with annual sales in the billions. Firm size may influence the way automation changes the work environment because large companies have the resources to tailor technologies to suit management's goals. The agricultural implements manufacturer, for example, worked extensively with vendors before installing an FMS suited to its production requirements. In contrast, small companies such as the job shops are "receivers" of the available technology: they must select from the range of off-the-shelf products.

- union representation: unions represented workers at the three large companies but not at the metalworking shops. Union representation affects management's freedom to unilaterally redefine job classifications and alter worker responsibilities after the introduction of new technology. The hostility or friendliness of the labor relations atmosphere also influences worker and management attitudes toward new technology.

- financial health of the company: despite layoffs and sales reductions due to the recession, the agricultural equipment and commercial aircraft firms studied remain the dominant figures in their respective industries. The auto company, on the other hand, is only recently recovering from near-bankruptcy. As a result, during the first three years of the operation of its automated welding facilities, the company could afford few spare parts and little preventive maintenance. This may well have increased the downtime of the system and the pressure on the repair supervisors ultimately responsible for fixing it. Most of the seven job shops appeared to be in good financial condition and had purchased additional NC equipment within the last several years.

- current level of market demand: the agricultural equipment plants and the aircraft firm are producing at well below capacity because of slahops. Union representation affects management's freedom to unilaterally redefine job classifications and alter worker responsibilities after the introduction of new technology. The hostility or friendliness of the labor relations atmosphere also influences worker and management attitudes toward new technology.

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- current level of market demand: the agricultural equipment plants and the aircraft firm are producing at well below capacity because of slack demand. By contrast, demand has picked up recently for the auto company. The assembly plant visited is producing at capacity and has back orders for one month's worth of production. Demand at machine shops tends to fluctuate with demand for client industry products. Most of the shops visited serve military as well as commercial customers and have done reasonably well in the last few years.

- geography: the agricultural equipment plants in this study are located in a small midwestern city which the company's facilities dominate. The aircraft manufacturing plants lie in a medium size west coast city in which the company is also the largest employer. The auto plant and machine shops stand within an hour of major industrial centers. Geography influences the alternative opportunities open to production and skilled workers. The agricultural implements firm pays its production workers considerably above the area average and, as a result, even operators who do not like the changes brought on by automation may remain with the company. Few other local employment opportunities exist for engineers at the aircraft manufacturer. Unlike other west coast regions, engineers cannot shift from company to company in the area until they find a job and salary they are happy with since the aircraft company studied is the major high technology employer in the region.

III. STUDY METHOD

Defining the issues surrounding the impact of programmable technology on the work environment is a complex task. The characteristics of individual machines, the design of the system, the operating practices of management, and the response of workers together determine the work environment effects of programmable automation. At the auto company, for example, the integrated design of the automated system, the management decision to minimize buffers between successive operations, and the unreliability of individual pieces of the technology all contributed to high downtime and a highly uneven, machine-dictated, work pace. An aim of this study is to unravel the technological and social factors that influence the way in which programmable automation is used, and to show how these factors interact. Case studies are especially well suited to this kind of research. Only through extensive and direct contact with people at particular sites can the complexity of technological and organizational change be appreciated and understood.

The case studies reported here are based on 3- to 8-day visits by two researchers to three large companies, and 1-day visits to each of seven small machine shops. At all but the auto company, the researchers interviewed management from first line supervisors to high-level corporate managers. At the auto company, plant level engineering management was interviewed at the site, but corporate manufacturing management interviewed only by telephone. The group and individual interviews with management were loosely structured and open-ended. By tailoring the questions to the particular person or group interviewed and leaving the interviews open-ended, the researchers could follow interesting leads and gain deeper understanding of the perspective and opinions of each manager. A tape recorder was used for most of the interviews at the small shops and aircraft company and for most of the worker interviews at the agricultural implement and automobile companies. Whenever possible the quotations below are based on transcripts of the taped interviews. All of the companies visited and all labor representatives were extremely cooperative, allowing the research team to interview any managers and visit any areas requested.

Workers were interviewed through the company and, at the large companies, through the union. At the auto plant and some of the small shops, access to the workers through the company proved particularly good, providing an opportunity to interview workers in private interviews in the plant. At the three large companies, the union arranged for interviews with workers at the local union hall. Union officials, generally shop stewards or committeemen, selected workers from the automated areas studied most closely. The interviews with workers were conducted in the same open-ended way as those with management. In particular, the researchers sought to elicit the issues workers thought most important before pursuing a more prepared line of inquiry.

Given the dearth of previous studies of how these technologies affect the work environment, this study aimed to identify the important qualitative issues in the area. No attempt was made to do any quantitative analysis of the study's findings. The sample of people interviewed was relatively small and nonrandom, and the interviews explored a variety of issues within a defined range, rather than following a standardized format. To statistically analyze the responses where it could have been done (for example, with a sample of 21 machinists from small shops) would have given the results an aura of definitiveness they do not merit. It is hoped this study will pave the way for more quantitative research by defining the important issues.

All the firms are anonymous and the names of any individuals working at or closely related to the companies under study have been changed.

IV. PROGRAMMABLE AUTOMATION IN THE FOUR CASE STUDIES

Small Metalworking Shops

This case investigates the introduction and use of numerical control in seven small metalworking shops in Connecticut. Six are machining shops and one is a sheet metal fabrication shop. The shops, like many other small job shops, work under contract to other companies and have no commercial product of their own. The chief client industries of the shops are aerospace, electronics, and defense.

Small machine shops face a highly competitive market and demand that is sensitive to the business cycles of the industries they serve. Although the commercial aircraft industry has been in a slump recently, only two of the firms visited had laid off a significant number of workers in the past two years. An equal number have enjoyed substantial recent growth. (For a schematic representation of some of the principal characteristics of the shops, see table 1.)

The central production technology in these plants is numerical control, one of the most mature and sophisticated of programmable technologies. Developed for the Air Force in the early 1950's, NC has now diffused to a broad range of other industries. Numerically controlled machine tools substitute an electromechanical control system for human control, although the process by which an NC machine tool cuts metal is identical to that by which a manually operated machine tool performs the same task. In the case of NC, however, a preprogrammed code directs the machine operation, while on a manually operated machine an experienced human operator executes the planned cuts. With NC, the exact order of all machine operations must be determined in advance and then translated, often with the assistance of a computer, into machine readable code. Generally, the preparation of these machine instructions or part programs is done away from the machine by a part programmer. Computer numerical control, a refinement of NC that was developed in the mid-1970's, brings a computer to the machine controller. This technical change opens up new organizational possibilities, because the machine instructions can now be altered (edited), or even prepared, at the machine itself. Whether the machine is NC or CNC, as the program is read by the electronic controller, the machine's operations are guided by servo-motors which take over the function of hand-cranking or manually controlled motors on a conventional machine.

All the shops used NC or CNC to perform precision metalworking, sometimes at close tolerances. The shop owners spoke of a number of technical advantages of NC over conventional equipment. These advantages include:

- The machining of complex parts. Difficult-to-machine geometries and part configurations are possible with NC because the computer develops the machining path.
- Repeatability. Once a program has been tested, all subsequent parts will be made in the same way.
- Fewer fixtures and setups. Since computer control allows the machine to duplicate complex motions, fewer expensive fixtures are needed to orient the part in a special way to the cutter.
- Increased flow of production. Since all operations are preplanned and fewer setups are required, an NC machine spends more of its time cutting metal than does a conventional machine.

When managers were asked why they had invested in NC machinery, two social and organizational issues were prominent among their motivations in addition to the technical benefits mentioned. The first was a shortage of qualified machinists. Three of the seven shopowners viewed the difficulty of finding skilled workers as an acute and pressing problem. NC was thought to be a partial solution to the skill shortage because of its ability to transfer skills from the shop floor to a part program, hence depressing the level of skill actually needed to operate the machine. The second motivation in acquiring NC was better control over shop operations. The predictability of the technology led to more accurate production cost estimates when bidding for new jobs and more reliable delivery times. Moreover, the ability to centralize an important element of planning in the programming department gave owners the option of specifying the exact procedures for the execution of work and thereby centralizing authority.

Agricultural Equipment

Beginning in the early 1970s the company, a midwestern manufacturer of agricultural implements and construction equipment, began the installation of a wide variety of computer-based systems in one of its principal businesses, the manufacture of tractors. Today the company is regarded as one of the leading users of programmable automation in medium batch manufacturing. This study focuses on two of the company's plants that have been widely recognized as examples of the company's pioneering automation efforts: the components plant and the nearby tractor assembly plant, both located in a city that is a center of the company's operations.

The company and its subsidiaries manufacture, distribute, and finance the sale of a full range of farm equipment and a broad range of earthmoving and forestry equipment. In 1982, the company had worldwide sales of over $4 billion, most of which were sales of agricultural equipment, predominantly large tractors and grain combines. The company has 11 factories in the United States as well as several abroad.

Spurred by an increase in the demand for its products, the company has spent over $2 billion on capital improvements since 1970, approximately half of which has gone into modernizing and expanding facilities in the State in which the plants studied are located. The company has significantly increased its market share over its competitors since 1978, but the decline in demand for farm and construction equipment has meant that the company's factories are now operating well below capacity.

The two plants in this study are both organized by the United Auto Workers (UAW). Relations between the company and the UAW have historically been quite good

-- or at least more amicable than in most farm implement and industrial equipment firms. The reaction of workers to the introduction of programmable automation is also shaped by the company's incentive pay system. This system has helped create an extraordinarily highly motivated work force. Machine downtime is not welcomed by incentive workers because it lowers their earnings, and employees use considerable ingenuity to keep machines running.

From management's point of view, programmable automation has been vital to the company's success in an increasingly competitive industry. The technology has resulted in increased flexibility to respond to rapidly shifting market conditions, better product quality, and higher productivity. An important element of higher productivity has been the transformation of what management saw as a series of difficult-to-control stop-and-go operations into a more tightly controlled, centrally directed "even flow" of parts reminiscent of operations in continuous process industries.

The manufacturing plant visited by the research team is an enormous complex of over 6 million square feet of floor space and employing about 10,000 people at capacity. Seven miles away, the tractor assembly plant includes 2.1 million square feet and employs about 2,500 people. In 1981, the assembly plant was given an important award by an engineering society in recognition of its pioneering computer integrated manufacturing system.

To explore the effect of programmable automation on the work environment at the company, three major systems were selected for closer examination: management information systems, particularly a labor reporting system that is used in both facilities; the material handling system in the tractor assembly plant; and the flexible manufacturing system (FMS) in the manufacturing plant.

Computerized monitoring and scheduling systems provide management with significantly increased amounts of information about shop activities. The goal according to a manager in the manufacturing plant is to provide "credible, consistent information throughout the organization" while the production activities are taking place. The labor reporting system collects daily labor data from employees such as the number of parts produced, hours worked, and time spent on a given job. Employees punch the information into computerized terminals in their work area. This data is then instantly available, in a variety of formats, on video screens in supervisors' offices. At the touch of a button, for example, a supervisor can see how many people are working in the department and at what time they clocked in.

In the tractor assembly plant, nine minicomputers operate ten systems that move materials through the plant and control various operations. The minis are capable of communicating with each other for purposes such as transmitting messages concerning part availability. Of the systems in the tractor plant, the materials management function has undergone the most dramatic transformation. There are seven computer controlled high-rise storage systems in the factory. Most parts arrive first at the largest of these systems, located in the receiving building. It is over 80 feet tall, has 16,000 storage compartments, and is served by six computerized cranes. Parts are moved from these storage areas throughout the plant on a computer controlled interplant delivery system.

One of the most sophisticated installations in the manufacturing complex is a flexible manufacturing system (FMS). The company purchased its FMS to manufacture the transmission case and clutch housings on its most recent generation of top-of-the-line tractors. This system combines NC machining centers, automatic part transfer, and overall computer control into a highly integrated production network. The FMS is targeted for midvolume production, combining the flexibility of NC machine tools with the constant "flow" of fixed automation. The flexibility of the FMS was of particular value to the company because marketing projections for part volume changed four times during planning for the system. Moreover, the system will remain useful beyond the next tractor model change.

The final design of the FMS included nine CNC machining centers, three head-changer type machining centers, and computer-controlled chain driven carts. Nine different part types in varying quantities can be routed through the system simultaneously. The computer automatically shuttles the part to the appropriate machine that has the shortest queue. If one or more of the machining centers are down, the part can be rerouted to a different machine. Once a part is loaded, it is theoretically untouched by human hands until it leaves the system.

On the day shift the system is staffed by 11 production workers and 3 supervisors, with fewer people assigned to the system on the other two shifts. At the load station, a video display screen tells a loader which part to clamp into a fixture. Within the system itself, each operator is assigned to three machines. The operator is responsible for changing tools when instructed, inspecting parts, responding to any unusual problems, and cleaning the machines. For most routine tasks, the system determines the timing.

Commercial Aircraft

The manufacturer of commercial aircraft that is the focus of this study is a division of a larger aerospace corporation. Both the division (which will be referred to as the company) and its parent are widely regarded as being at the cutting edge of both product and process innovation in the aerospace industry. The study has a dual focus: the first part explores the use of computer technology to revolutionize the organization of work, principally in the design and engineering of the airplane, and the second part looks at NC machining in a large production machine shop. The study took place in several facilities, including an engineering center and the machine shop, near the company's west coast headquarters.

The company sold 78 percent of commercial jet transports in the noncommunist world in 1980; the percentage declined to 48 percent in 1982. The company is now banking its future on two new jets: the Epsilon and Zeta. Though the jets are of different sizes, and are aimed at different markets, 60 percent of the significant line replaceable items are the same for both aircraft.

Most of the corporation's employees in its concentration of west coast facilities belong to two unions. The International Association of Machinists (IAM) has about 24,000 members, and an independent professional association of engineers, scientists, and technicians has about 19,000 members at the company. The IAM represents over 90 percent of the eligible workers in its jurisdiction, and the professional association represents about 60 percent of its potential bargaining unit. The introduction of new technology has become an important bargaining issue, and the IAM has introduced its demands in the form of a "Technology Bill of Rights."

CAD

CAD is defined quite broadly at the company as the use of computers to generate and evaluate designs, drawings, and other information throughout product engineering and manufacturing. Interactive computer graphics, the latest CAD systems, allow a designer or engineer to "talk" to the computer through a keyboard or light pencil and receive immediate feedback on a cathode ray screen. On the most advanced systems, the engineer can construct three dimensional solid models which can be rotated, enlarged, viewed in cross section, and manipulated in countless other ways, all in a stunning range of colors. Once engineers define the geometric model, engineering analysis can be done, including calculations of moments of inertia, weight, volume, and stress. Test systems can evaluate how a component or even an entire airplane perform under simulated conditions. Finally, drawings can automatically be produced.

The company maintains the use of CAD has resulted in a number of important benefits. These include:

- Elimination of routine work. The computer now does many calculations and operations that were formerly done manually.
- Access to current design. Instead of having to produce and circulate a new set of drawings, users of CAD terminals can modify the data sets to which all relevant engineers have access, making revisions instantly available to others in the company.
- Reduction in errors. The increased coordination and better communication means errors are more likely to be detected and earlier in the design and manufacturing process.
- Faster iteration. Designs can be revised more frequently and more experiments carried out with design alternatives.

A central thrust at the company is to link the separate design, business, and manufacturing computer systems into a centrally directed, integrated whole. The goal is to create a controllable stream of information governing the development and production of the airplane from the point at which the airplane is first designed to the point where it finally lifts off the runway. An increasing number of manufacturing decisions will also be made by integrated teams of designers and engineers before the design is finalized. Using CAD, the geometry of the airplane will be mathematically defined, electronically encoded, and then launched into a computerized network for use throughout the rest of the company. Everyone else in the design and production of the airplane will work from this data stream and be constrained by these initial decisions. One manager referred to this as "putting the smarts up front."

NC in the Production Machine Shop

The NC machine shop covers an area of 471,000 square feet, about the size of 10 football fields. Some of the NC machines in the shop are as much as two stories tall, so large that the operator has an elevator that runs up the side of the machine, since some operations require access from above. All together, there are 110 NC and CNC and 230 conventional machine tools in the shop. The shop currently employs 630 machinists.

NC has made it possible to remove from the shop floor much of the decisionmaking involved in part production, taking a substantial amount of discretion away from those at the point of production and moving it earlier in the design/build process. Many of these decisions are now made by part programmers, of which the company employs over 100 for its various NC operations. However, as in the small shops, the operator retains the critical control over the speeds and feeds at the machine.

One important technological difference in the large machine shop, when compared to the small shops, is the presence of a computerized paging and monitoring system which allows increased oversight of shop operations by management.

The Auto Company

This case examines the application of robots to the spot-welding operations in an auto company's assembly plant. A robot is a programmable arm which can move simultaneously along a number of axes at a range of speeds, and has an attachment that rotates and grips like a human wrist and hand. The evidence from the auto plant suggests that the breadth of focus of the study is critical: considering only the robots themselves highlights the nature of the jobs they eliminate; a broader focus on the automated system of which the robots are a part explores the quality of the remaining jobs in the system as well.

The company investigated in this study floundered badly in the late 1970's due to the shift in consumer demand toward small cars. Its inability to change over rapidly to fuel-efficient car production and its financial vulnerability, led the company to the edge of bankruptcy in 1979. Extensive Federal loan guarantees, a change in management, substantial employee wage concessions, and concessions from suppliers prevented bankruptcy, and the company's fortunes are now improving.

At the time of the visit to the plant in May 1983, some tension existed between the UAW and the company nationally. Wage concessions had left the company's workers earning approximately $2 an hour less than those at other major automakers. Now that the company is profitable again, the union wants workers' wages raised to the industry average. On a local level, workers complained about increased pressure on the job.

In 1980, in response to the increase in consumer demand for small cars, the company designed a new model which required a $60 million retooling at the plant visited. The bulk of the retooling took place in the framing side of the "body shop," where sheet metal parts of the car are welded to each other. At the heart of the automatic framing operations is the "Robogate" system. Robogate is a single fixture or "gate" that holds the sides, underbody, and other parts in place while eight robots apply spot-welds that set the dimensions of the body. Most of the other robots in the plant apply "respot" welds which increase the mechanical strength of the car.

Robogate has a number of major technical and economic advantages over previous methods of welding. First, dimensional consistency of the body is assured because only a single gate is used for each car type. Before Robogate, each car body was held by one of 18 different gates while main assembly (or frame) line workers hand-welded the parts together. Variation in the dimensions of the gates produced variation in the dimensions of the bodies produced by the framing lines. Second, Robogates improve the strength and quality of welded frames because there are fewer missed welds and robots place their welds in the same place in each body. Third, Robogates reduce retooling costs substantially by cutting the number of gates and clamps that have to be purchased for each new model.

The automated area consists of two major components: the subassembly areas where parts of the sides and underbody are welded together, and the "main frame" line where the sides, roof, and underbody are welded by Robogate and 32 respot robots to form the complete car body. The case study focused on the side aperture and main frame line where the 64 robots are located.

Before 1980, workers in subassembly joined large pieces of the side with a combination of automatic welding machines and hand-welding guns. Each subassembly work station was independent of the others: the parts they produced would go into piles by their machines and then directly onto one of two oval conveyors -- the "side-gate" loops. Between the two loops, the side-gates would "marry" to an underbody carrier called the body truck, before traveling down the main frame line.

In side aperture today, most workers stand at automatic welding machines, lift several parts off racks or the floor and place them into a fixture, then hold down a palm button for several seconds while automatic clamps close and the machine welds the parts together. Next, they lift the welded part out of the machine and load it onto a hook on a conveyor or gravity feed. The conveyor and gravity feeds between successive operations have room for about 18 to 30 parts. About halfway through side aperture the sides are loaded onto a monorail carrier (monotractor) that is programmed to stop at the side aperture robots and various work stations before proceeding to a 45,000 square foot buffer storage area or directly onto the main frame line.

The company has sought, through the design of the system and through directives, to minimize inventories. The director of manufacturing engineering at the corporation maintained that reducing inventory at the plant can improve productivity and quality. Without inventory between separate operations, workers cannot speed ahead and possibly, in his view, jeopardize quality. Moreover, any quality problems that do result can be spotted immediately. The drive to reduce inventories is based on the Japanese "just-in-time" or "kan ban" concept, in which supplies of parts arrive immediately before the parts are needed for assembly. The engineering director stated that this approach eliminates costly inventory which occupies about 20 percent of the floor space in a traditional plant.

At the beginning of the main frame line, the two sides and the underbody are "toy-tabbed" together by a group of seven workers, these workers hammer tabs in each part into slots in adjacent parts to hold the body loosely together. Next, the Robogate and six respot robots apply 56 stabilizing welds to establish the dimensions of the frame. Ten workers then manually weld on the roof, and add additional interior welds. After this the bodies move past the 32 robots in the automatic respot (ARS) line.

The body shop buffer stores a total of over 120 underbodies, finished bodies, and side apertures of each kind. An overhead conveyor carries the parts and assembled bodies to and from the buffer, while stationary fork lifts raise or lower them to available storage space. The buffer is intended to provide insurance in case either the subassembly or final body assembly operations suffer downtime. Any third of the body shop can theoretically continue for up to 2 hours (depending on how full the buffer is) if problems occur in one of the other thirds.

V. FINDINGS

Increased Interdependence

A striking feature of many of the systems observed in the course of the company visits was their high level of integration. The Robogate system at the automobile manufacturer, the materials handling system and the FMS at the agricultural implement maker, and even the simple--by comparison--technology of stand-alone NC machines represent a substantial increase in the extent to which individual production operations are tied together into a larger system. One consequence for the work environment resulting from the introduction of highly integrated systems is an increased interdependence between workers who deal with these systems.

Both production and maintenance workers in batch production commented on the extent to which they increasingly were linked to others in the workplace. For production workers, this interdependence chiefly meant that at certain stages of production, the input or participation of others was required, so that teams rather than individuals were necessary to complete a job.

For subassembly production workers in the auto body shop, interdependence increased because each individual was more closely tied into the pace of the system as a whole. One subassembly worker explained:

> Before you had more individual operations. Jim might work over there where he makes his little thing, and the other one might make his little thing, and everybody made their little thing and you might have maybe two people working together. Well, now you have maybe five, six, seven, eight...and everybody dependent on everybody.

The higher degree of integration in side aperture results in more synchronous work for all production workers, making it impossible for individual operators to work faster or slower than others in the system for more than several minutes.

On the FMS, too, interdependence increased because operators are now responsible for a system, not just for a single stand-alone machine tool. While different operators were assigned to different areas of the system, there was a greater need to coordinate with the system superintendent in the computer control room and with other operators. Operators also reported helping each other out when things were slow in one area and more workers could be useful in another area.

Even stand-alone NC operators, both at the aircraft manufacturer and at the small job shops, commented on their increasing need to rely on programmers and other support operations. An NC operator at the aircraft company said:

> On a conventional machine it's pretty much just between you and the machine. Somebody brings up a tub full of parts and says, "Here it is. Go to it." On the NC machine you've got the programmer, you've got NC tooling, you've got planning, and if any one part of it breaks down, then the whole thing goes.

A supervisor in the same shop also felt the effects of this increased interdependence. "Supervising NC, you have to deal with more support groups. You're more vulnerable to their preferences. There's more negotiation beforehand with people like programming and fixturing."

At the small machining job shops, there were fewer support groups than at the large aircraft production machine shop, but operators still had to coordinate with the programmer who wrote the parts program when a new tape was being tried out. More often than not, in the small shops, changes in the tape were made either by the programmer or in consultation with the programmer. No longer could a machinist execute an entire part alone, as was generally done on conventional machine tools.

Maintenance workers experienced the increased interdependence in their work chiefly as an increase in the need for collaboration among the different skilled trades. The complexity of the new systems meant that, in many cases, diagnosis and repair required the input of workers of varying backgrounds. A skilled tradesman at the agricultural implement maker described the situation:

> You can save a lot of time by people working together and getting along. Otherwise a two-minute problem becomes a two- hour problem. A few years ago you could do it by yourself but now you need two heads, one mechanical and one electrical, and a good operator.

Both maintenance workers and operators commented about the necessity for closer collaboration between the two groups in the repair of complex, automated machinery.

Less Autonomy in the Work Place

In all of the work sites visited, managers spoke about using programmable automation to establish better planning and allocation of all the firm's resources. A frequently-mentioned benefit in batch production was faster throughput, the ability to complete the production of a part in less time, as a result of more effective direction of the part's movement through the shop. The particular organizational choices managers made to establish greater control resulted in less autonomy for the workers involved. This section reviews some of the consequences of these choices.

This reduction in autonomy was described by workers in many cases as leading to more stressful and less satisfying experiences at work. Stress, discussed in detail in a separate section, derived from such factors as the decreased individual control over work pace, increased monitoring, and the responsibility and pressure of working on a complex and costly system. Satisfaction was reduced in cases where workers felt that they had lost substantial input into how the product was produced.

The exact nature of the effect on autonomy varied among workplaces. Skilled machinists running NC machines in small job shops, for example, mentioned reduction in job satisfaction resulting from a substantial decrease in their input to how the part was made. In workplaces where jobs were already highly rationalized even before the introduction of programmable systems (for example, at the automobile assembly plant), workers did not have the same sense of input into the finished product to start with. In these cases, issues such as the ability of a worker to control the pace of work were central.

Although automation is generally designed to minimize human intervention, the research team observed that, in practice, varying amounts of human input were needed to sustain efficient production. The need for this human input tends to increase the amount of informal control and hence the autonomy that workers exercise in the workplace. Thus, there was a contrast on the shop floor between the level of operator intervention anticipated by the system's designers, and the actual amount of operator intervention that takes place.

This section looks at the reduction in worker autonomy that results in several computerized situations: the use of NC and the tendency to move production decisions off the shop floor, the monitoring of shop floor activities, the attempt to provide an "even flow" to parts production, and the goal of establishing a "controlled flow" of data in design and production.

Numerical Control: The Location of Production Decisions

NC machines, because they run off of a preplanned program, offer management a previously unavailable choice about who in the shop will do the detailed planning of the work that will be executed by the machinist. The choices range between the following two alternatives:

1. The machinist plays a major role in the programming process. This might include doing the initial programming of the part or the subsequent editing of the program. On conventional equipment, this is a central part of the machinist's trade. The development of CNC, which allows editing and programming at the machine, facilitates this choice.

2. The programming is done by a full-time programmer off the shop floor. This centralizes the detailed planning of work, which was decentralized in conventional shops, and allows tighter control over production operations.

In some cases, there are compelling technical reasons for doing the programming off the shop floor. Some parts programs are very complex and can be written only by someone able to devote careful attention for many hours to the process of constructing the program. In other cases, it is more efficient for programming, and particularly editing, to take place on the shop floor. Because the machinist is the person closest to the cutting process itself, improvements can be more effectively incorporated into the program.

The choice as to where programming should be located is influenced by social and organizational issues as well as by technical considerations. Among the seven small metalworking shops visited, there was considerable variation in the organization of production and the locus of decisionmaking and planning activity. These variations resulted from factors such as the complexity of the machining operation being planned, the value of the part, the batch size to be produced, the operator's programming skills, the programming method used, and the goals of the owner. One shop, for example, rotated some machine operators through the programming department. Another shop allowed substantial latitude for prototype machinists to do programming.

In spite of the existence of variations, however, the owners of all of the shops had chosen to move in the direction of more centralized control over the production process. In addition to overall process planning and scheduling, which has always been the province of the owner in a small job shop, these small shops used NC equipment to move the detailed planning of work off the shop floor. The vast majority of the NC programming in some shops, and all of it in others, was done by a programmer rather than by the machinists. The desire of shop owners to exert greater control over shop operations and their belief that sufficiently skilled workers are not available were undoubtedly important drivers in these organizational decisions.

In the machine shop of the aircraft company, programming was also primarily done off the shop floor in a large programming department. An important difference from the small shops was that both the programmers and the machinists were unionized, although in different unions. On the one hand, this gave both groups potential leverage to actively influence their work environment, including who should do programming and editing. On the other hand, some machinists were concerned that editing and programming by machinists might violate the job security of the programmers.

Removing planning from the shop floor takes away a central element in the machinist's job and reduces the worker's autonomy. The machinist becomes a machine tender, waiting to intervene when something goes wrong, rather than an active participant in production. For highly skilled machinists this loss of autonomy was viewed as a key drawback of operating NC. One skilled machinist at the aerospace company commented:

> You don't have to think anymore. You lose touch with what you're actually doing because everything's been told. You've got a set of documents, you've got your tapes, and you've got a set of instructions as to how to set the machine up and run it, and I believe you yourself become a robot because you don't get to use your mind.

In both the large and the small shops, when machinists were officially allowed to program some machines, these machines tended to be subsidiary to the main machining activity in the shop. For example, a machinist might program a lathe in a small shop whose primary machines were milling machines. The same was true of the aerospace company. Machinists in the drill area and several other smaller operations did their own programming. In many of the shops visited, however, informal programming and editing were reported, regardless of any formal prohibitions. This intervention was often motivated by the desire of machinists and first line supervisors to maintain efficient production. At the aircraft company, for example, if there was an urgent need for a particular part, and no programmer was available, the machinist might make the necessary corrections in a faulty program. Also, most shop owners and supervisors admitted that the operator's active intervention was often necessary to optimize the part program.

Monitoring the Shop Floor

The increased visibility of shop operations made possible by computerized monitoring and scheduling systems allows management to spot bottlenecks more readily and take corrective action when necessary. There is, however, another dimension to the collection of information that goes beyond the coordination of production: what information is gathered and how it is used can result in new forms of control, both subtle and direct, over worker activities. This control results in less autonomy for workers and sometimes for supervisors on the shop floor. The study explored two systems that oversee shop floor behavior: an electronic monitoring and paging system at the commercial aircraft company and a labor reporting system at the agricultural implements company.

One of the functions of the electronic monitoring and paging system is to monitor production at 66 NC machines which are directly wired into the system. The goal is to improve machine utilization, particularly by ensuring that the machines are run close to the programmed feed rate. A machine is automatically designated as being in one of four states: running, running at less than 80 percent of the programmed rate, down, or temporarily halted for part handling. The system and a panel that shows the status of each machine is housed above the shop floor in a control room with a view of the surrounding machines. By looking at the panel, a supervisor can tell the status of all the machines in a given jurisdiction. Moreover, supervisors obtain daily reports from the system, and weekly and monthly tabulations are made in chart form for upper management as well. The goal is to establish direct feedback from the shop floor to management about how an important element of the NC program--the control of machine feeds--is carried out.

Today the system appears to be widely accepted even though some operators are apprehensive about its monitoring capabilities. One of the reasons for this acceptance is that certain limits on its use by management are fairly well established after several years of operation. The company has an agreement with the union that information from the system will not be used to discipline employees, although operators said that individual supervisors could exercise various sorts of informal discipline if they chose to. Because the control room overlooks the shop floor, workers have nicknamed the system "the spy in the sky."

The Terminal Labor Reporting System is used to collect personnel- and production-related data in the two plants of the agricultural implement company visited by the research team. After completing a job, stopping work for other reasons, or going on or off incentive pay, the worker keys this information into a terminal near the work area. The same terminal is used for punching in and out. At a touch, a supervisor can call up detailed information about every aspect of the department's activities. One supervisor viewed the system as a "major enhancement for looking at attendance, earnings, and absenteeism. Something has to happen every hour of every day with an employee. Everybody in the factory has to be someplace and this is the tool we use to find people."

Since workers in the plant are on an incentive system, there is a built-in motivation to avoid downtime and maintain production. With this reporting system, however, a supervisor gains insight not only into the total number of parts produced on a shift, but how the worker actually spends the time. This capability can be used to ensure that workers follow established methods on jobs, or in those cases where the worker has developed a superior system, to see that the jobs are retimed and the incentive rate changed. A further target of the system is "banking", a practice where a worker accumulates a stockpile of parts by working faster than the prescribed methods. This bank can then be used to even out incentive earnings when things are not going well. From the company's point of view, this violates established job procedures and results in excessive inventories.

In this case also, the union had reached agreement with the company in these plants that the data collected from the system would not be used for disciplinary purposes. Although most workers appeared to accept the system, there was apprehension about the monitoring capabilities. One worker graphically described these fears:

> It's 1:00 and I'm not done until 3:30 so I go over and I punch my work in that I've got 24 pieces done, and they happen to go in there and the computer tells them that "Hey, this operator punched in his work at 1:00, how can he punch in his work before he's done?" In other words, that computer is saying, "Hey, this guy got done at 1:00." That scares the hell out of me.

With a system such as the Terminal Labor Reporting System the supervisor also loses autonomy in several key areas. Since many transactions are entered into the computer--such as when a machine is down and a worker is off incentive earnings--the foreman no longer is able to wink at after-the-fact corrections. The system can be used to break up any informal arrangements supervisors and workers have over shop floor practices, even those informal arrangement that may increase productivity. For example, at the agricultural implement manufacturer, a worker whose machine was down for repair might take a "bonus" day off. Although these contractually-provided floating holidays are supposed to be applied for a week in advance, under the old system a supervisor would sometimes backdate requests, since it would have been costly to have the worker stand around while the machine was being fixed, and the day off would have been taken eventually in any case.

Even Flow

The design of some systems shortens the throughput time by physically controlling the progress of a part through a series of manufacturing operations. Two such systems visited were a flexible manufacturing system (FMS) at the agricultural implements company and an automated welding system at the automotive company. In seeking to more closely control the processing of the part, the activities, and hence the autonomy of the production workers involved, became more constrained.

Technically speaking, an FMS is only capable of producing those parts that the NC machines around which it is built are capable of producing. It is able to utilize those machines more intensively than stand-alone operation because complex computer algorithms control the allocation of parts to the various machines and then automatic carts transport, load, and unload the parts at the machine. If a machine is down, the computer reroutes the parts to the remaining machines in an optimal way.

The system is designed to minimize the intervention of the operator. The project manager on the system maintained, "You don't have people you're relying on. Once the computer gets the part, it doesn't wait for a guy who is drinking a cup of coffee." The manager of mechanical services at the plant concurred, saying "people become the exception here instead of the rule." The manager of manufacturing engineering added that "the automatic loading and unloading of the system is a significant advantage. The quality level is no longer dependent on the skill of an individual operator. Now a certain minimum quality level is built in."

FMS operators' jobs are different from the jobs of stand-alone NC operators in that there are fewer points in the production process at which their intervention is routinely required--in the loading and unloading of parts, for example. However, some predictable interventions, such as tool changing, are still required, and the FMS keeps track of tool wear and signals when a tool change is scheduled. Also, the systems supervisor in the FMS's control booth directs the operators to trouble spots that develop in the system. While the FMS operator deals with more machines than the stand-alone NC operator, the FMS operator is constrained by being a part of a larger system, and being called upon to respond to the system's and the supervisor's signals.

While the system is designed to operate with minimal human intervention, a visit to the FMS and interviews with operators and with managers suggests that considerable operator input remains necessary. Given the extraordinary complexity of the entire system, the project manager admits that a considerable amount of "tender loving care is necessary," above and beyond routine duties. A tow pin on the cart might stick or an operator might spot a broken tool in a part. At times there are also tool adjustments the operator must make to meet critical tolerances. A number of supervisors commented that the operators are very quality-conscious and that the system would not work effectively without them. An operator can see a defect in a part, according to one supervisor, and know where the machine went bad. He further maintained that "a good operator develops a feel for the machine. Just by listening he can tell if a drill is going bad or a bearing is going out."

The Robogate system ties subassembly jobs into a line by arranging them serially and connecting many of them with conventional conveyors and an overhead monorail. In pre-Robogate days, workers could carve out blocks of free time to break the monotony of the day by accumulating banks, and thereby enjoyed some control over their work pace. Production supervisors did not object because the accumulation of parts could ensure uninterrupted service during a breakdown. The new system is designed in a way that makes banking more difficult. Moreover, the company has issued directives to workers to stop stockpiling parts. The company's ultimate aim in subassembly appears to be to replicate the rhythm and control of the main welding line. Consequently, subassembly workers complained of having to work throughout the day at a pace defined within narrow limits by the machines.

Controlled Data Flow

At the airplane company, the attempt to move creative decisionmaking to as early a point as possible in the design/build process results in less autonomy in jobs that subsequently handle the data. As one engineer put it: "The idea is to try and control the data and the system so that everybody does everything the same way. Many jobs will simply be eliminated by the move to a computer-controlled data flow. Among the jobs that remain, broader and more creative jobs will be available to those engineers who are at the beginning of the design/build process, while those "downstream" in the data flow will be more constrained. The co-director of a CAD/CAM integration group at the airplane company described the effects.

> A number of the people that are left will be an element of a very controlled process. The ingenuity of the craft will have been removed. The advantage is to have more consistent outcomes with the hiccups removed. People's actions will be more controlled by strict procedures. The human part of the job will be less evident.

Skill

The Effect on Skill Requirements

It is important to distinguish between the overall level of skill required by the system, including all operations necessary to plan the work, operate the equipment, and perform maintenance functions, and the skill level of any given job. The level of skill required for any job will be a function both of the overall requirements of the system and of the organization of work in the firm. In looking at the effects of the implementation of programmable automation on skill, operators and maintenance workers will be treated separately, followed by a discussion of changes in the occupational structure and work organization in the firms studied.

Skill Requirements for Operators: The clearest evidence of an effect of programmable automation on skill requirements for operators came from the small metalworking job shops included in the study. Shopowners all reported that the use of NC allowed them to run their machines productively using workers with less skill than they would have required on conventional equipment. The use of NC did not make machinists' skills superfluous, nor did it eliminate the need for some highly skilled workers in the shop, but it did allow the shop to function with a lower overall skill level in its work force than previously possible. As one owner of a precision machine shop said:

> We have found that the one thing that NC equipment and CNC equipment has done is basically that it has transferred the skills to some extent from the person to the machine. So we now have been able to take people who have native mechanical ability who have never seen the inside of a machine shop before, train them, and they are excellent operators...For those people who have not taken advantage of the technological changes, who still run the old style shop where you're dependent upon tool-and-diemakers, they are hurting, because there aren't any tool-and-diemakers being trained by anybody to speak of.

Shopowners saw NC as one solution to the skill shortage which they believed they faced, a shortage which made it difficult to find highly skilled machinists in the local labor market. Although some shopowners exhibited a strong commitment to training--out of necessity, they said--most seemed to believe that training highly skilled machinists themselves was beyond their resources, and that a technological solution--the purchase of NC equipment--was their alternative.

Although NC allowed owners of small job shops to run their machines productively with less-skilled workers, most owners stressed the fact that they believed that machinists' skills remained important even on NC machines. The vice president and head of manufacturing engineering at one shop said:

> The type of work we do takes a good toolmaker or a good machinist. He has to monitor it, has to adjust sizes. Drawings are complicated; he's got a lot of responsibility. He's responsible for producing the whole part...We use our most skilled people on NC. When you take a small business and invest that much money into a piece of equipment, we don't want to save two dollars an hour by putting an unskilled operator on it. The higher skilled the operator is, the more we get out of the machine.

Because of the inherent unpredictability of small-batch machining, such as was found at the small job shops and at the aircraft manufacturer, it is not possible to rationalize work to the extent necessary to make machining jobs fully routine.

Particularly with difficult-to-machine alloys in unusual cutting situations (frequently found in aircraft production), the skill acquired by a machinist during years of experience can be crucial to the production of good parts. In particular, both shopowners and skilled machinists said that the skills of a machinist who had considerable experience on conventional machines were of value on NC machines. With simpler parts in higher volume production situations it is possible, through the division of labor and the use of jigs and fixtures, to reduce the machining skill necessary on both NC and conventional equipment; but in small and medium batch production of complex parts, NC reduced the necessity of having machining skill without making such skill valueless.

The level of skill of machinists and degree of autonomy previously exercised on conventional equipment--for those who had such experience--affected their attitudes toward the use of NC equipment. Those machinists who performed routine production work on conventional machines generally liked NC, observing particularly that it provided cleaner and physically lighter work. Highly skilled workers who had a high degree of autonomy on conventional equipment generally disliked running NC machines, and believed that running them required little skill and provided no satisfaction. One very experienced machinist said, "You get to be, in my opinion, on an NC, a little weak-minded." Another said, "They're junk as far as I'm concerned...You can take a chimpanzee, the light goes on, push a button." Only the skilled machinists who were able to do some programming work at their shops expressed an interest in and enjoyment of NC machining.

Highly-skilled machinists also expressed concern about the effect of the widespread use of NC machines on their craft. They believed that NC removed much of the skill and satisfaction inherent in machining work.

> (Using conventional machinery) that's where you get your skills, your knowledge. You feel like you're doing something. When you take a raw piece of material and look at the blueprint, and whether it be three weeks, a month later, and that's a finished part, and you look at it and say, I made that. Tape (NC) machine didn't make that. I turned all those handles. I figured out how to do it. I ground the cutters to make the radiuses and the angles. And when you're finished with it, and somebody says, "That's a nice job," that's satisfaction.

Because the use of NC reduced shopowners' reliance on highly skilled workers, it also reduced somewhat the leverage that skilled workers had in setting the terms of their employment. One shopowner said,

> Five, six years ago we were very dependent upon skilled labor, to the point where I spent half my life on my hands and knees begging somebody to stay and do something. And they tended to be prima donnas: "I don't work Saturdays" and "I don't work nights." And this is one of the motivating factors in bringing in NC equipment. That reduced our dependency on skilled labor.

Skill Requirements for Maintenance Workers: At the tractor manufacturer and the automaker, programmable automation made some maintenance jobs broader and more challenging. In both places, maintaining the computerized control systems requires electronics expertise and problem detection skills of a different variety than those necessary for conventional equipment. An electrician at the tractor manufacturer said:

> These machines are all computer controlled. It's a lot more complicated than fixing a radial drill. Ten different things can cause the same symptoms. The breakdowns are more software oriented; they're diagnostic problems.

A welder repairman at the auto company expressed similar sentiments: "With basic (weld) guns, you've got basic weld repair. With robots you got everything from electronics, to hydraulics, to computers...I don't think you'd find a man here who'd refuse to do this work. It's broad; everybody likes the job. They love it."

The Effect on Occupational Structure

In addition to changing the skills required to do a particular job, the introduction of programmable machines and systems may also change the relative mix of skills required within the organization as a whole. In a small metalworking job shop, for example, the introduction of NC does not eliminate the need for varying degrees of skill within the organization, but it does mean that fewer highly skilled workers are required.

At the aircraft manufacturer, a striking reorganization, affecting the company's skill requirements throughout its engineering operations, was projected. According to the architects of the reorganization, the establishment of the "data stream" would make the jobs done earlier in the design-build process broader and more technically detailed, while reducing the autonomy and need for skills later in the process. At the same time, many relatively routine jobs--perhaps as much as 30 percent of the indirect labor in the company--could be eliminated. If accomplished, this would bring about a substantial reconfiguration of skill within the company.

In the body shop at the automaker, there has been a distinct rise in the ratio of skilled to production workers. This is due to displacement of production workers as well as the increase in skilled maintenance labor.

The Organization of Work: A new organization of work has arisen in NC machine shops, as the result of the creation of the position of parts programmer -- a job that incorporates the planning work previously done by skilled machinists. There remains a significant overlap in knowledge between parts programmers and skilled machinists, to the extent that almost all of the parts programmers in the small machine shops, and most of the programmers at the aircraft manufacturer, were former machinists. While programming is in some sense a "new" occupation -- created by the possibility, which NC presents, of splitting off the planning of work from its execution -- many of the skills of a good programmer are also present in a highly skilled machinist. At the aircraft company, machinists who worked on CNC machines were particularly conscious of the fact that it was technically possible for them to do programming work at their machines, and that their skills, combined with the capabilities of their machines, allowed them to "put the programmer out of a job," as one machinist said.

Although programming as an occupation was created by the advent of computerized technology, it seems also to be threatened by new developments in computerization. While it seems that CNC -- which allows programming work to be done more easily by the machinist -- generally is not used for shop floor programming, from a technical point of view that possibility is now more real. Also, new developments in computerized design and programming systems -- such as the system at the aircraft manufacturer that will automatically generate a tool path given a set of parameters, or the system at the machine shop that allowed parts programming without special computer language training -- dramatically increase the productivity of programmers or, in a few cases, eliminate them entirely. The substitution of machines for human programmers was seen both at the large NC machine shop at the aircraft manufacturer and in the small shops, all of which had computerized programming systems in-house.

Boredom

Boredom was a common complaint among NC operators and also to some extent among operators on the FMS. Features of the design of the technology, combined with relatively narrowly defined jobs, meant that for many operators there were periods during which attentiveness, but little active participation in production, was required. Skilled NC operators who did not write parts programs (that is, the vast majority of NC operators), reported that operating an NC machine was significantly less interesting and challenging than operating a conventional machine. FMS operators found the complexity of the system interesting, but many aspects of their jobs were relatively routine.

Boredom as a Consequence of Machine Design

Both NC machine tools and the FMS are designed to run with minimal operator intervention. The operator intervention that is planned into the system is of a relatively routine sort--tool changes, for example. Yet both the owners of small shops with NC machines and the project manager of the FMS acknowledged that operator input of a more than routine sort was important to the smooth functioning of the production process. The need for alert and intelligent operator intervention is at odds with an aspect of the system's design: the attempt to remove, to the extent possible, the necessity for intervention. Especially for machinists making long cuts on NC machines, operators reported being bored for significant periods of their working day. An NC machine operator at the aircraft manufacturing company said:

> The hardest thing to do is to keep yourself on your toes checking the measurements. Just because the tape says it's good, it's not necessarily so...You get to relying on that tape, and what the machine can do, and sometimes the boredom-you know, you'd just as soon put another part on and just sit down again.

The boredom inherent in running a machine that can function automatically for periods of time is exacerbated in some cases by long running times for individual parts, so that there may be a matter of hours and sometimes even days between changeovers when a new setup is required. Parts with long running times are particularly common in the aircraft industry, so that machinists at the aircraft manufacturer and at the small shops that were subcontractors to the aircraft industry encountered many parts requiring lengthy cuts. Large lot sizes, which demand that an operator make the same part repeatedly, also were a factor in boredom. At the small shops, some relatively inexperienced NC operators who had been machinists for only 2 or 3 years were interviewed; they reported fewer problems with boredom, indicating that a worker's previous experience is an important factor.

On the FMS, boredom appeared to be less of a problem for operators, but this may have been a function of the broader range of problems to which the system was subject. The larger the number and variety of unanticipated events, the less opportunity there was to be bored. As with operating an NC machine, the slower periods when FMS operators appeared to be idle were actually times when they were overseeing the system and watching for problems. At these times, boredom could set in because there was a lull in the need for their active intervention and problem-solving skills. These periods of relative inactivity alternated with periods of considerable stress and pressure when problems arose with the system, because operators participate in the diagnosis and minor repairs of the costly and complex system.

Boredom as a Consequence of the Organization of Work

Some of the boredom operators complained of is the product of the extent to which operator intervention and control are eliminated from the technology by design. In addition, within the limits set by technical requirements, managerial decisions about the organization of work on automated machines and systems may contribute to or reduce the sense of boredom. One of the most vivid examples of how the organization of work in automated workplaces can affect the quality of the work environment comes from the allocation of programming work in an NC shop. While it is technically possible for NC machinists to do their own programming, at least for simpler parts, shop floor programming was rarely found, either in the small jobs or in the large NC machine shop at the aircraft manufacturing company. By removing programming from the shop floor, the most interesting and creative part of machining work has been taken out of the hands of the machinist. Because it is not possible today, given the current state of the technology, to dispense with the operator altogether, a certain amount of machine-tending will be necessary. Yet it is also true that if, to the extent technically feasible, the responsibility for decisions about how to make the part were placed with the operator, boredom would be reduced. A machinist in a small machine shop said:

> How could you make the job more interesting? With a machine like this [an NC lathe], get a good operator who knows what he's doing, and you give him a chance to do a setup, and learn how to program the machine, so that he can look at the readout, and he can understand what the machine is doing; not just stand here and just wait and then push the button and take the part out. That would help for a while.

Even involvement in programming will not eliminate completely the boredom of long running time. An inspector who runs an NC machine at the aircraft company said, "I like to run the computer and figure out the programs and what needs to be done, but I am bored once you take over the machine and start checking a part."

Another example of the removal of creative decisionmaking from jobs involves the projected changes in engineering jobs at the aircraft manufacturer as CAD is used more widely used. It is possible that one of the consequences of the reduction in autonomy and the decrease in opportunities to contribute in meaningful ways to the production process will be the increased incidence of boredom for engineers not filling the broad and creative jobs at the beginning of the design/build process.

Stress

Work-related stress was a significant feature in computer-automated workplaces. Evidence from worker interviews suggests that for many workers stress is becoming an important factor in the work environment, particularly for employees who have responsibility for very complex and expensive systems. During the course of this study, two major sources of automation-related stress were identified. First, there was stress associated with working on very complicated, capital-intensive, and highly integrated systems. Second, the lack of autonomy at work, extending in some cases to computerized monitoring by management, was a reported source of stress.

Complex, Expensive, and Highly Integrated Systems

At the plants studied, maintenance workers and operators who had some maintenance duties reported substantial stress associated with having the responsibility for a sophisticated, costly, and interdependent automated systems such as the Robogate system or the materials handling system at the agricultural implements manufacturer. The combination of the complexity of the system (which maintenance workers at the automaker and in the tractor assembly plant reported finding challenging but also stressful) and the pressure to minimize downtime because of the high cost of lost production, added up to substantial stress for some maintenance workers assigned to systems of this sort.

The most vivid example of this type of stress is in the body shop at the automaker, where welder repair supervisors reported being under extreme pressure. In the side aperture/Robogate/APS area of the body shop, there had been a 150 percent annual turnover rate among first line supervisors. A general foreman said: "This has been the hardest three years of my life. There isn't any relaxation...I've walked out of here and sat in my car, unable to move, getting myself together." He continued "(the pressure) it takes its toll. On good people, smart people. No babies. There is no one who will upgrade anymore in this department."

One of the chief sources of pressure is the highly integrated nature of the automated framing system, which links in series complex electronic and mechanical components. A failure in one part of the system spreads quickly to other areas. The old welding line in the body shop was also highly integrated, but the individual parts of the system were more reliable, and there was more backup equipment that could be put in place of a failed component of the system. In addition, repair work was comparatively straightforward.

The expense of the equipment in the automated body shop is a further source of stress. Thousands of dollars worth of damage may be done if a supervisor, in haste, misdiagnoses a problem. A welder repair supervisor commented, "If I do not grasp the situation immediately, I could destroy a hand-gear train...All it takes is one push of a button. In the last three weeks, I lost two hand-gear trains." Each hand-gear train costs $6,500.

Similar pressures are present on the FMS at the agricultural implements manufacturer. This, too, is a very complex and highly integrated system which represents a sizable capital investment for the company. The system has both operators and maintenance workers assigned solely to it. In addition to their regular duties, operators function somewhat like maintenance workers in that they troubleshoot in response to calls from the systems supervisor in the control room, as well as looking for potential problems on their own.

On the FMS, too, problems tend to spread rapidly.

> On a line like this a small mistake can quickly become a big mistake. They tend to think you shouldn't make mistakes so that the supervisor comes down hard. After you make a mistake you're scared so it gets so you can't do your work.

Unlike, for example, the Robogate system, the FMS is designed so that there is redundancy among the machine tools at the heart of the system. If one machine is down, there is likely to be another available, and the system is programmed to route parts to other machines in the event of a machine failure. This technical feature of the system's design may serve to reduce somewhat the pressure on repair personnel, at least by comparison to the Robogate system where an unreliable buffer serves as a backup. An operator describes, however, the not infrequent case in which more than one machine is down at a time.

> The pace they try to set is the biggest problem...they still hurry people, and they don't expect you to make mistakes, and yet they increase the chances of making mistakes by hurrying you, and I've had that happen to me. I was working on one machine when the other one's down and they want to get that one going and there isn't too much wrong with that first one, so I jump over there quick and set this tool quick and go back and then I goofed up. I set it wrong or something, and that's what happens when you hurry your guys.

The complexity and expense of the system also made some operators apprehensive. As one operator put it, "When you're first down there, you're just nervous. Because everything's so expensive you don't want to break anything. You tear up a boring head and that's $80,000 not counting the production you lose." Another source of stress for workers on automated systems comes from the unpredictability of complex systems. Computerized automation, as an electrician at the tractor assembly plant said, "is made to go and stop on its own program." A machinist at a small machine shop made a similar comment about working on NC machine tools:

> These NC machines--they're unpredictable. You don't know what it's going to do, the first time you run that program. You're always on edge until it's proved out.

At the auto company, a welder repair general foreman said:

> ...if [the robots] get off a flange, or they skip a program, they won't tell anybody. That's the disadvantage. They have to be watched...There's things that can happen, that are lurking. It's follow up, follow up constantly. You can't relax altogether and rely on it.

Stress from Lack of Autonomy

The reduction in autonomy at work can take its toll in stress on the worker. Analyzing studies of Swedish and American men, Dr. Robert A. Karasek found that work-related strain was a function not of heavy job demands alone, but of the combination of heavy job demands with restricted job control and decisionmaking latitude. He concludes:

> ...the opportunity for a worker to use his skills and to make decisions about his work activity is associated with reduced symptoms (of stress) at every level of job demands. We do not find, therefore, support for the belief that most individuals "overburdened" with decisions face the most strain in an industrialized economy. Literature lamenting the stressful burden of executive decision making misses the mark. Constraints on decision making, not decision making per se, are the major problem, and this problem affects not only executives but workers in low status jobs with little freedom for decision...(such as) assembly workers, garment stitchers, freight-and-materials handlers, nurse's aides and orderlies, and telephone operators.[7]

The various ways in which the introduction of programmable automation has been used to reduce the autonomy of workers is discussed in some detail above. For the purposes of this section, it is important only to note that one of the costs to the worker of decreased autonomy may be increased stress. Workers who are restricted in their ability to control their jobs may, as Dr. Karasek's work suggests, suffer from stress and even from illness as a consequence of the organization of their workplaces.

A few particular aspects of the lack of autonomy deserve mention here. One is the presence of machine-paced work, such as was found at the agricultural implements company and at the auto manufacturer, the two companies with the largest batch sizes of those studied. Assembly workers at both companies were paced by the speed of the line, so that both the rate of their work and the timing of their breaks was out of their control. At the auto company, downtime caused unpredictable stops in the line. A worker described the effect of the machine pacing and its variation, "What you're doing is you're going and stopping, going and going, running and going. You know what that does to your insides? It changes your whole system."

Electronic monitoring of worker performance, and the apprehension it engenders in workers, also adds to the stress of the workplace. A machinist at the aircraft company said of the electronic monitoring and paging system, "It's like having a big television camera looking over my shoulder." Monitoring, not a new issue on the shop floor, was also an emerging issue among engineers at the company, because of the potential use of CAD terminals for monitoring the amount of time spent at the terminals by individual engineers.

Finally, workers at the components plant operated by the agricultural implements company expressed concern about the erratic flow of parts through their areas, which they attributed to problems with the introduction of a computerized scheduling system. While the company maintains that there are no significant problems with the scheduling system itself, the level of discontent expressed by workers suggests that, if nothing else, there is a significant problem of communication about the new system and how it is meant to function.

Downtime

Popular and trade press accounts of automation rarely mention that computer-controlled technologies break down. But they do. In particular, the body shop welding operations, the tractor works materials handling system, and the flexible manufacturing system all reportedly suffered significant downtime. Problems in the interaction of computer control, electrical signaling devices (used to tell the computer what position and condition equipment is in), and parts transport and storage systems caused much of the downtime in each system. The computers controlling these systems and, to a lesser extent, even the individual machines in them (e.g., the robots and NC machines) had very few electrical or mechanical problems. In all three systems, integrated design produced a "domino" effect: the effects of breakdowns in one place would rapidly spread throughout large areas, increasing the cost of each minute of downtime.

The high downtime observed does not imply that automated systems are unproductive or inefficient. On the contrary, the high throughput of automated production lines means that, even with high downtime, total output usually increases. The high throughput results, in part, from the elimination of machine stoppages as a result of factors under human control in a conventional shop. For example, on a stand-alone NC machine the operator loads a part that is delivered by someone in material handling. On the FMS the part is automatically shuttled between machines and loaded or unloaded based on an algorithm that theoretically should result in the most efficient shop operation. Ironically, seeking to eliminate too much human intervention can be a contributing cause of downtime, since complex systems are necessary to replace human input and these systems are subject to problems.

While erratic and unplanned downtime may not imply that automated systems are inefficient, it can cause a deterioration in the work environment: production workers suffer the aggravation that comes with an oscillating work pace, and maintenance workers feel the stress associated with responsibility for bringing the system back up quickly.

When examining downtime and its effects, it is important to distinguish problems which arise during the "debugging" of a complex automated system from those which are endemic to the system. At the auto and farm machinery companies, separating these factors is extremely difficult because the systems are relatively new. A lot of debugging has certainly been done already; downtime at both places is much lower than it was after the first year of operation. It is also true that downtime on the FMS, the automated materials handling system, and the Robogate system is falling slowly, if at all, at present. It seems likely that the persistent level of downtime will be significant.

The designers of the automatic framing system anticipated downtime of 20 percent, according to the welder repair superintendent in the auto plant. Downtime currently fluctuates between about 17 percent and 22 percent in both side aperture and on the main frame line. The manufacturing engineering manager appeared satisfied with the system's performance: "Most automation systems, you aim for somewhere in the range of 15 to 20 percent downtime. Overall, we operate within that range." Before the installation of Robogate, downtime in the body shop averaged 3 to 5 percent, according to supervisors who were working there in 1979.

The principal causes of system downtime in the body shop have been the conveyors which carry parts down the line and to and from the buffer, and the buffer itself. For example, the equipment which raises parts to and from the overhead conveyor frequently malfunctions, and the photocells on the line sometimes miscount the number of carriers that pass them and signal the computer to let too many bodies fit between two points. As a result, the carriers become jammed and will not move properly.

Repair workers and supervisors emphasized the integrated design of the system and the complexity of the electronic equipment when they talked about downtime. The welder repair superintendent stated: "Everything is tied together now. When one part goes down, it affects many more operations than it did in the past. If one limit switch goes down in ARS, you can tie up the entire line." A production supervisor put it bluntly: "If one system's dead, the whole system's dead after a while." While system downtime has been high, the robots themselves have performed extremely well in the body shop, averaging more than 95 percent uptime.

Several factors have exacerbated downtime at the auto company in the recent past: the inexperience of welder repairmen, the difficulty of buying spare parts because of the company's financial troubles, and production at full capacity. Improvement in the first two factors may bring with it a reduction in downtime. On the other hand, the removal of the buffer storage area, while it will eliminate some causes of downtime, will also hasten the spread of problems throughout the body shop and to the rest of the plant.

At the farm machinery manufacturer, workers and managers disagreed about the reliability of both the materials handling system and the FMS. While management did not regard downtime as a problem, many workers spoke of persistent and annoying difficulties. One assembler who is a union steward claimed:

> The difference between the new plant and the old plant downtown is the amount of downtime. Our quota is 48 tractors a shift but the line is run at a speed that would turn out 53. Those extra five slots are put in because of all the delays we experience...In the two years that assembly line has been in operation we haven't had a perfect day except for one day...Some days like yesterday we only got 36 tractors when we were supposed to have 53.

Most breakdowns in the materials handling system appear to be caused by failures in the storage and delivery system. The area just before the painting bay causes particular problems. In this area, eight models on three separate assembly lines are fed into a surge area where they are moved through a single paint line and out into three assembly lines. Four cranes must unload the three chassis assembly lines and load the final lines in correct sequence. As one worker put it:

> Those big cranes out there for some reason get the wrong instructions from the computer. They'll crash into each other, or maybe they'll let the front end of the chassis down and not the back end down. I've seen them fall off that big crane.

The integrated nature of the operation makes the failure of any machine linked to the plant-wide delivery system a more serious problem than the failure of stand-alone machines. An electrician described what happens:

> When one part of the system stops, it all comes to a screeching halt. If the line goes down, all the people on the line stop working. All the conveyors bringing parts into the line have to stop, and all the people feeding those conveyors have to stop. Whoever the individual is who does maintenance in that area has to get it all going.

Some workers felt that the situation could get worse when higher production is run, particularly on two shifts. One worker "looks forward to it getting better." He maintained, "We said it would never work right. It's amazing how well it does work."

Unlike the other two systems, the FMS at the tractor plant is designed to minimize downtime. If a machine is down, parts are automatically rerouted to other machines in the system. On the other hand, if the transport system goes down, the consequences are more severe. The system's designers anticipated 33 percent downtime. Management provided various figures on downtime that ranged from 4 percent to 20 percent but some workers believed downtime to be higher. While the research team was there, a malfunction of a machine air conditioner caused the machine to go down, and then further problems delayed startup for about 45 minutes. On the following night several hours of additional downtime was reported. Weekend work was scheduled to make up for lost production, but a software failure caused this to be cancelled as well.

As on the two larger systems, small problems have a tendency to snowball, or as an operator put it: "On a machine like this, a small mistake very quickly becomes a big mistake." When the line is stopped, for example, the carts tend to drift from preset positions so that the computer loses track of their precise location. This necessitates a more elaborate startup.

NC machines in the FMS at the small shops and at the aircraft company reportedly perform reliably, although exact figures were not available. An early problem limiting the diffusion of NC machine tools was reliability, but improvements in electronic controls seem to have effectively solved many difficulties.

Safety

In two of the four cases reported here--the aircraft company and the small shops--NC machinery was the only production technology examined. As a result, the findings below regarding automation and safety on the factory floor must be regarded as very preliminary.

Popular conceptions of automation suggest automated factories are filled with workers who stand back and watch as machinery produces part after part. Based on the evidence of this study, the field record of automation with respect to safety appears to be mixed. On the one hand, some types of automation remove production workers from close contact with tools during actual operation. On the other hand, automated carriers, clamps, and fixtures move and close without direct human initiation and sometimes without warning. This can be particularly dangerous in highly pressured settings: e.g., for maintenance workers who deal with complex equipment on an assembly or processing line that cannot start again until they finish repair work.

Three different field examples suggest that automation can improve safety by increasing the distance between workers and the part being machined, assembled, or processed: the introduction of robot welding means that auto production workers need not work near the point of contact between weld gun and sheet metal, which produces showers of sparks. On NC equipment, machinists work at a greater distance from cutting tools. At the agricultural implements firm, robots rather than workers spray-paint tractors in an atmosphere filled with fumes.

While some automation may reduce hazards during normal operation, programmable equipment also introduces a host of new safety problems associated with the complexity, unpredictability, and automatic nature of new equipment. A worker at the agricultural implements firm said of an automated system:

> I've seen the thing move and nobody touched a button. You're dealing with something you can't control. It's created a whole different type of problem--not necessarily more problems--but different problems.

An electrician expressed similar sentiments: "Sometimes you can shut a machine off to work with it, and sometimes you can't. Once you correct the fault, it's liable to kick off."

Supervisors, union officials, and the company safety representative at the auto plant agreed that automated machinery can increase the severity of injuries. In the words of a production superintendent: "Before you could get a nick, now you may get mangled."

The danger of injury has escalated most for repairmen who work with equipment that cannot be pulled to one side and replaced by a backup, but must be fixed before operation can begin again. According to the auto company safety administrator:

> In the old days, you had one gun, and you could shut it down and work on it. Now you got this complicated mess. If you don't know what you're doing, you could get hurt. We've had press injuries you didn't have before, and automatic clamps."

A welder repair general foreman at the auto plant said: "(Welder repair) has had more injuries since Robogate than we had before, quite a few more. Broken toes, a broken ankle, falls."

The danger grows when production pressure is intense. The auto company general foreman told of an injury he suffered under heavy production pressure:

> I fractured my skull on a Robogate trying to get six bodies through by midnight because that was the edict. I hit my head on the corner of a control box. I felt like I had a hole in my head.

Cleaner and Lighter Physical Work for Operators

Operators of computer-automated manufacturing technologies reported that their jobs were cleaner and involved somewhat less physical labor than on comparable conventional equipment. A few of the dirtiest, heaviest jobs--for example in the foundry and on the paint line at the tractor manufacturer and in the welding area at the automaker--have been eliminated entirely. A union steward at the tractor assembly plant said that he welcomed the automation of the painting job, as long as it did not result in unemployment.

> I think some of the new technology is probably good, like the robot for painting tractors. That was one of the dirtiest jobs here. Being in the pit painting, you had to paint all day long.

At the auto manufacturer, a production worker who had worked as a welder in subassembly and on the main line described how arduous the job had been: "I remember when I welded floor pans. I had two big guns that I pushed around...I was in the pit welding side frame, and that was a rough job. I mean I caught hell doing it." The worker continued, "Those jobs, I think it was better that the robots took over." The Robogate system also eliminated manual movement of the heavy gates that were previously used in the welding operation on the main assembly line. The new jobs created by the introduction of Robogate, those of the "tabbers" who hammer together the parts of the body in preparation for its passage through the line, involve physical work but do not require as much heavy lifting as the movement of the old gates did. Some "tabbers," however, complained that they now work harder because they are doing more work in a shorter work cycle.

Some of the jobs that remain after the introduction of programmable automation have been made less physically arduous as a result of the introduction of the technology. Operators of NC machines stated that, compared to conventional machines, NC required less physical manipulation and reduced the amount of setup work necessary. The two groups of operators who found this aspect of NC particularly attractive were older workers and less skilled workers who would have been performing relatively routine sorts of work on conventional equipment.

Operators on the FMS also liked the reduction in heavy work. Once within the system, parts on the FMS are loaded and unloaded automatically. One operator said, "There is little physical work here compared to a tape (NC) machine that you have to load yourself." The heavy jobs that remained were those of the loaders, who mounted the parts to be machined onto carts in preparation for their entering the system, and unloaded them as they left the system. While these jobs had a great deal of physical labor involved, the total amount of physical effort was reduced for the system as a whole, since each part was only handled by a human worker twice in its travel into and out of the system.

Both operators on the FMS and the operators of NC machines commented on how clean the work was relative to working on a transfer line (in the case of the FMS) or on conventional equipment (in the case of NC operators.) On the FMS, the area is bathed in coolant, thus minimizing the soot that is associated with cast iron machining on conventional systems. The increased cleanliness of NC machines is not a function of the use of a computerized control system, but instead is the consequence of the mechanical design of the machine: because NC machines are built to run at high speeds and feed rates, they are built more solidly than most conventional machine tools; the larger NC machines even have a metal and glass door which can be closed during the cutting process, to separate the machinist from the chip and coolant that is scattered while the machine is running.

Training

There was widespread concern among workers on automated machines about what they perceived to be inadequate training for their jobs. Production workers on assembly lines, such as those at the tractor manufacturer and the automaker, had not had the content of their jobs affected by automation, and therefore would only have been interested in training as a route to promotion within the company. At a time when the work force at both these companies was being cut back, upward mobility was less of a concern than simply keeping ones present job. Consequently, most of the desire for training was expressed by workers who felt they needed more instruction for their present job.

Each of the three large companies had had an apprenticeship program in the past, but two had suspended their programs at the time of the study and the third had reduced the size of the program. Some of the small job shops had apprentices working for them, but they did not have their own apprenticeship programs. Instead they made use of a state-sponsored apprenticeship program which provided a few hours a week of supplemental training. In the small shops there were no complaints from workers about the adequacy of training, even among relatively inexperienced workers who were not in apprenticeship programs. This may have been because employees in small shops did not expect the employer to provide training, as workers at a large company might, or perhaps because there was more informal training in small shops. In any case, the chief complaints about training came from operators and skilled trades employees at the large companies.

Some of operators' interest in learning more about the machines they ran was motivated by curiosity about new computerized technology. Most often, however, operators felt that their lack of training about the capabilities of their machines made them less productive workers. The most vocal group of operators were machinists in the NC shop at the aircraft company. Although the company sponsored after-hours courses for employees, the operators reported that these classes did not address the specific capabilities of their machines. Moreover, the training took place on the operator's own time. One machinist described his experience of training at the company, a view consistent with that expressed by other machinists:

> I have to teach all three of these guys to run my machine and vice versa. Now how can I teach them when I don't know? If I haven't come upon something that my machine can do, then I don't know about it...They put a new machine in, I learn it, the first shift learns it from the guy who installs the machine, then he teaches the next shift and that is how we learn to run it. Nobody has come in and taught me to run my machine.

NC operators were distressed about not knowing more about the capabilities of their machines, feeling that they could produce better parts if they were better versed in the use of their equipment. Another machinist from the NC shop said:

> It's like having a DC-3 pilot and walking him over to a 747 and saying, "Now look, guy, it's an airplane, too--use it to the fullest extent it was made for." That's what we're talking about. "And if you don't know how to fly it then check with the guy in the right seat because he has probably been in it before and he will show you how the ropes work."

Some maintenance workers also complained about inadequate training. Maintenance personnel are expected to repair increasingly sophisticated and complex electro-mechanical equipment, and most of the maintenance workers interviewed felt inadequately prepared. Compounding their sense of inadequacy was the rate of technological change, which could quickly make even recently-learned systems outdated, and the pressure they felt to repair speedily the costly and complex technology.

Maintenance workers felt that their needs for training were not being adequately addressed. In a study of an FMS operated by a competitor of the agricultural implements manufacturer in this study, Donald Gerwin of the University of Wisconsin-Milwaukee School of Business Administration, and Melvin Blumberg of the Fairleigh Dickinson University School of Business Administration, describe the company's attitude toward the skills required of maintenance workers.

> The complexity of the new technology is staggering (even to one of the authors who is a graduate engineer). Yet, electricians are being told that since computers are electrical, they should be able to repair them after several weeks' schooling at the vendor's facility. Mechanics who have never had to deal with anything more complex than a gear box are suddenly expected to diagnose and repair a state-of-the-art, electro-hydraulic and mechanical device costing on the order of 8-10 million dollars and not completely understood by its designers.(4)

Although an extreme case, this description is consistent with the sentiments reported by maintenance workers assigned to highly automated equipment.

Finally, one of the additional forces motivating workers' interest in further training is the fear of displacement as more and more jobs are affected by automation. The statement of an operator on the FMS, who had bid onto the system partly because of his concern about being left behind by changing technology, was typical. "If you don't get into it, you won't be able to get by. If you're looking at 15 years or so before retirement, you'll be sweeping floors."

Displacement

At the companies visited during field work for this study, managers maintained that automation has been vital to their company's survival or growth in the recent recession. In management's view, economic success is the surest route to job preservation and creation. On the other hand, as a consequence of automation, all the companies visited can produce more output with fewer people. In market conditions such as those of the past few years, increased labor productivity can mean fewer jobs.

It is not the purpose of this study to assess whether the net effect of automation is higher growth and more jobs, or higher productivity and fewer jobs. Rather, its purpose is to evaluate workers' perceptions of displacement and consider the effect of these perceptions on the work environment. At the three large companies, many of the workers interviewed raised the issue of displacement caused by the introduction of automation. Their apprehension about the security of their own jobs affected their feelings about their work. A worker at the agricultural implements manufacturer spoke of the uneasiness that stems from the feeling that you may be the next to be cut:

> We've got 4,500 people laid off. We've got some people that'll never be called back to their jobs. And part of it is because through the new technology there isn't the need for the amount of manpower as there has been in the past. Therefore you've always got in the back of your mind, "Well, am I gonna be next?" You take that on top of worrying about whether your plant is going to be the next one to be shut down. Overall, when you start compounding it with everything else, I think it puts a lot of stress on what I call the average worker.

A production worker in the auto plant suggested that high national unemployment and the fear of further layoffs have made workers willing to accept an intensification of work:

> I'm going to tell you what our problem is basically. "Thank God we got a job"...Because everybody takes that attitude now, "Thank God I got a job. Work me to death if you want to, work me like a mule. At least I got a job.

Like the operator at the agricultural equipment company, the auto worker said his fear of unemployment stems from the job loss associated with automation:

> It has a lot to do with automation. When they brought this automation mess in here, we knew they were going to eliminate some jobs. Ain't no doubt about that. But I don't think nobody expected it to be the way it was. Every other time when they've laid people off, people have come back. When they laid people off this time, we expected them to come back...Automation means fewer jobs, right. That's what they're doing. They've got automation and there's fewer jobs.

Machinists at the small shops seemed less anxious about the security of their jobs. While there had been some layoffs at the shops in recent years, none of the shops had undergone recent layoffs of large fractions of their work force such as had taken place at the three large companies. Also, many interviews were held with skilled machinists for whom there are projections of excess demand well into the future.

VI. CONCLUSION

Programmable automation offers extraordinary promise to improve the work environment by making possible more skilled and creative jobs. The findings of these exploratory case studies suggest that in many cases this promise has not been realized and that in some cases the quality of the work environment has clearly deteriorated. In those situations where the work environment has not improved or has been made worse, the negative effects do not stem from any inherent properties of computers but reflect the specific design and organizational decisions that have been made. The fact that programmable automation has improved the work environment in some cases--such as the new opportunities CAD provides to senior engineers--makes it clear that the possibility exists for expanding and enriching jobs through provision of new capabilities and the enhancement of skill.

An important question is whether improvements in the production process must come at the expense of the work environment. Although a system now in place degrades the work environment, this cannot be regarded as proof that a system that enhances human capabilities and improves the workplace would be less productive. While issues of productivity were beyond the mandate of this study, there seemed to be a contradiction between the fact that machines were designed to be fully automatic and the fact that these machines required, at times, substantial human input. This contradiction raises an important question: does machine design facilitate human corrections for machine failure in an optimal way or does the desire for fully automatic operation constitute a roadblock to effective operation? The technical choices available are not limited to totally automatic operation on the one hand and random, uncoordinated human intervention on the other, but include a range of possibilities that combine human control and computer technology. If humans must intervene, and it is difficult to do so, the result could be additional stress on the job. Automated systems whose design does not take into account the human operator may not only negatively affect the work environment but harm productivity as well. In some cases, however, a more efficient process may in fact come at the expense of the work environment. If this is the case, the dimensions of the tradeoff are important: what amount of additional productivity is achieved at what expense to the working environment? Whether the tradeoff is worth it is primarily a social rather than a technical issue.

While change may be inevitable, there is nothing predetermined about the nature of technological change. Where the design of a system has negative effects on the people who operate it, it is important to consider whether alternatives are available. One cannot conclude from the present organization of production that those choices, particularly as regards the working environment, made by companies in the process of instituting computerized systems were the only ones available. Alternative methods of organizing work in computerized workplaces, both as these options exist in actual workplaces and as they might exist under somewhat different circumstances, offer important directions for future research. An examination of the potential solutions to the challenge of shaping the automated workplace will provide a more detailed sense of the relationship between the quality of the work environment and the demands of effective production.

The findings of these exploratory case studies suggest a variety of additional avenues for future research. It would be valuable, for example, to conduct systematic quantitative investigations of computerized workplaces, in an attempt to discover how generalizeable the findings contained in the four case studies are. To what extent are the research team's findings particular to the companies or to the industries studied? How are the issues different and similar in white collar workplaces? Which programmable technologies are most often associated with a given effect on the work environment? How typical are the reactions of workers interviewed for this study to changes in the work environment? Can any generalizations be made, based on survey research, about the factors that influence worker response to changes in the work environment?

As industrial change accelerates, these issues surrounding programmable automation and the work environment will become increasingly important. The technological possibilities exist to make work more creative and satisfying. Whether these possibilities are realized will depend on more than the technology alone.

FOOTNOTES

1. Although computer technology is inherently flexible, the way programmable machines and systems are *designed* can encourage some forms of work organization and discourage others. In fact, certain organizational goals such as more even flow of production or less human intervention may be embodied in the design of technology itself. The factors influencing technological design, however, are largely beyond the scope of this study.

2. Robert A. Karasek, Jr., "Job Demands, Job Decision Latitude, and Mental Strain: Implications for Job Redesign." *Administrative Science Quarterly* (24), June, 1979. p. 303.

   These findings are based on analysis of two large surveys, the Swedish Level of Living Survey and the University of Michigan Quality of Employment Survey. The Swedish study was based on a random sample of 1,896 members of the full adult male population, while the Michigan study is a national stratified random sample of household units, with responses from [illegible]1 adult men.

3. In a related study, Karasek and his colleagues report a link between low amounts of job control and an increased risk of heart disease. This study of 5,100 Swedish and American men found that the ten percent with the least job control were approximately five times as likely to develop coronary heart disease as were the ten percent with the most job control. The researchers felt that stress on the job formed the link between low job control and high risk of heart disease. (Bryce Nelson, "Bosses Face Less Risk Than the Bossed." *New York Times*, May 3, 1983.

4. Melvin Blumberg and Donald Gerwin, "Coping With Advanced Manufacturing Technology," Presented at *QWL and the 1980s*, Toronto, Canada, August 30-September 3, 1981, p. 6.

Table 1. Characteristics of Small Metalworking Shops Studied by OTA

	ALPHA	BETA	GAMMA	DELTA	EPSILON	ZETA	ETA
Total Employees	75	19	74	16	10	200	48
Employees on Shop Floor	[illegible]0	16	60	15	6	130	40
Annual Sales	$8.2M	$900,000	$4.5M	$600,000	$300,000	$25M	$2.75M
NC and CNC Machine Tools	21 NC and CNC	3 CNC and 16 NC	8 CNC for sheet metal	6 CNC	5 CNC	14 CNC and 30 NC	23 NC and CNC machines
Year First NC or CNC Machine Tool Purchased	1974	1966	1976	1976	1979	1957	ca. 1966
Principal Client Industries	military aircraft medical	varied. electronics, hydraulics, etc.	mostly electronics	electronics aircraft	aircraft medical	aircraft, both military & commercial	electronics aircraft
Programming System	Digital "APT"	Genesis "Encode"	Webber "Prompt"	Webber "Prompt"	Bridgeport "Easy Cam"	Digital "APT"	General Numeric "Numeridex"
Average or Typical Lot Size*	50	250-500	100	250-500	250	100	50
Size of Shop in Square Feet	23,000	10,000	30,000	8,000	2,500	66,000	28,000

*lot size figures are rough estimates only

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I. INTRODUCTION

Numerically controlled machine tools are among the oldest modern examples of the application of digital technology to a manufacturing situation. Developed for the Air Force in the early 1950's, numerical control is now in use in a broad range of machining workplaces, including many outside of the aerospace industry. In an attempt to understand how the use of this programmable technology has affected the work environment in small metalworking job shops, interviews were conducted at seven technologically advanced small shops. Numerical control (NC) and its more recent microprocessor-based successor, computerized numerical control (CNC), were found to have made possible significant changes in the organization of work, the employment practices, and the business strategies of every shop studied.

NC and CNC (which will be referred to collectively as "NC") substitute electromechanical control for control by a skilled human operator. Because of their technical capabilities, NC machine tools present the owners of small job shops with the option, previously unavailable, of removing from the shop floor much of the planning and decisionmaking work associated with the production of parts. In job shops without NC, machinists working on conventional machine tools do the detailed planning work necessary for the parts they will produce. In shops with NC equipment it remains technically possible for machinists to plan their own work, yet in every job shop visited for this study, owners had chosen to centralize control over the planning of work. This organizational change, permitted but not mandated by the technical qualities of NC machinery, carries profound implications for the work environment in job shops where NC has been adopted.

In small shops with considerable investments in NC equipment, the following changes in the work environment were generally found:

- The ability of owners to exert centralized control over shop operations, including the detailed planning of work, had been increased.
- A reduction in the overall skill requirements of the shop had taken place. Highly skilled workers were still needed, but in smaller numbers, and machine tools could be run by less skilled workers.
- Highly skilled workers running NC machines found their jobs more routine and boring. They also reported feeling the loss of a personal sense of accomplishment and satisfaction.
- Less skilled workers found their work less physically taxing because the amount of manual intervention had decreased. However, the prospects for substantially more skilled and creative work in the future were limited.

II. NUMERICAL CONTROL IN SMALL MACHINE SHOPS

All of the shops visited for this study were job shops, which provide machining services to other companies rather than having a product of their own. Although there is great variation among job shops with respect to the type of service they provide and their level of specialization, conversations with shopowners and with industry associations suggest the following generalizations: job shops exist in a highly competitive environment, are sensitive to the business cycles of the industries they serve, and have difficulty getting financing for new equipment. The success of a job shop depends on its reputation for quality and reliability, as well as on its prices.

Most shopowners described their market as extremely competitive. One shop vice-president, however, felt that by meeting rigorous quality standards and delivering parts on time, a company could establish long-term relationships with clients which would insulate the shop from the competitive market. The vice-president explained that manufacturers have to conduct lengthy tests to ensure that a shop produces parts of the required quality, and as a result are reluctant to shift away from established suppliers.

All members of the industry interviewed agreed that starting a job shop is very difficult at present. They said that the industry had become capital intensive rather than labor intensive in the last decade and that a large amount of financing is needed to start a new job shop. The owner of Gamma Manufacturing claimed that "10 years ago, you could start up a small shop in a garage with a Bridgeport," but now, witn the widespread application of NC, "the cost of one machine is greater than the cost it took to start up most of the firms in the industry."

Increasing capital costs are also affecting established shops. The same shopowner said that "the only firms expanding now are old-timers who have their machines paid off, and can afford to divert profits to buying new machines." It often takes 5 to 7 years to pay for new equipment, and since financing costs are so high, the only firms that are purchasing CNC are ones that can finance them internally.

NC machines were introduced into a small number of job shops in the 1950's and 1960's, but have spread more rapidly through the industry in the last decade. Between 1973 and 1976 alone the number of NC machines in Standard Industrial Classification 35 (machinery except electrical) increased 38 percent, and by 1976, 43 percent of all job shops (SIC 359) had at least one piece of NC equipment.[1] A representative of the National Tooling and Machine Association said that today it would be very rare for a shop with over 50 employees not to have at least one CNC machine tool.[2]

Historically, small metalworking shops have been slower to purchase NC than large ones. For example, by 1976, in SIC code 35 as a whole, 2.5 percent of the machines in large firms (100 or more employees), 1.8 percent of the machines in medium-sized plants (50-99), and 1.4 percent of the machines in small firms (20-49 employees) had NC controls. Geographically, there has been considerable variation in the NC diffusion rate. Firms in the area from which this study drew its sample, however, have purchased NC machinery at approximately the average national rate.[3]

Increased interest in NC among job shop owners has been partly the result of refinements in NC technology. Advances in computer technology, particularly microprocessors, have made NC equipment more flexible, more reliable, and have reduced the amount of special training and equipment necessary for their use. Improvements in both the hardware and software available to aid in programming NC machine tools have also promoted the spread of the technology. Initially, NC machines were not an economical alternative to conventional machinery for small job shops. They were chiefly used in industries that are not particularly cost sensitive (such as military aerospace or nuclear power plant components) for the manufacture of complex contoured parts that would have been difficult or impossible for a machinist to make on a standard machine.

III. METHOD OF STUDY

This study is based on visits to seven metalworking shops in Connecticut. The sites were chosen from a group of sites suggested by the Numerical Control Society, a trade magazine, and two interviewees at the job shops themselves. They were chosen to span a range of shop sizes. The shops were not chosen for study because of their "representativeness"; indeed, the chief selection criterion was that the establishment be particularly advanced, for its size, in the number of NC machines in use. Every shop contacted agreed to participate in the study. The final group of seven shops was drawn from a pool of eleven shops that agreed to participate.

Visits to the shops in the study lasted from one-half day to a full day. At each site, the researchers began by speaking to the president or vice president, generally for an hour or more. Subsequent interviews were held with programmers, foremen, working foremen, and shop-floor workers. For the most part, the people interviewed were selected by a manager or foreman based on the research team's preferences for talking to a cross section of the shop's work force. In cases where the researchers asked to speak to a specific person, these requests were honored. At some shops, the interviewers were invited to select any of the employees for interviews.

Interviews were open-ended, based on a prepared interview guide. Generally, interviews lasted from one-half hour to one hour, with the longest interviews running over two hours. Almost all of the interviews were tape recorded, with the consent of the interviewees, and most of the quotations used are based on transcripts of the taped interviews. Interviews were held at the plant, generally in an office or room. In some cases, interviews were conducted in the office of the president or vice president. With very few exceptions, the interviewers were alone with the interviewee. All interviews except one focused on one person only; at one plant, the president and vice president were interviewed together.

Altogether, four presidents, four vice presidents, five programmers, five foremen and working leaders, one quality control supervisor, one full-time machine repairer, and 15 machinists and operators were interviewed.

IV. THE SEVEN SHOPS DESCRIBED

Of the seven shops studied, six were machining shops and one was a sheet metal fabrication shop. Two were owned by small parent companies, while the rest were independent. The sheet metal shop and one of the machine shops had recently merged, although at the time of the visit they both remained in their original buildings and there had been no transfer of employees between the two plants.

The shops included in the study, despite the fact that they had in common their relatively small size and a high concentration of computerized technology, varied in many respects (see Table 1). Among them:

Size: The smallest shop visited had 10 employees, 6 of whom worked on the shop floor, while the largest employed 200, with 130 on the shop floor. Annual sales ranged from a low of $300,000 to a high of $25 million.

Equipment: Every establishment in the study had several NC and CNC machines. The number of NC and CNC machines ranged from a low of 5 to a high of 44, and every shop had CNC equipment in addition to NC. Every shop retained conventional machine tools, and in several cases the number of conventional tools substantially outnumbered the number of NC and CNC machines. Nevertheless, in every shop visited, the NC and CNC equipment was central to the operation of the shop. In the majority of shops, conventional equipment was used only for support operations for work done primarily on the computerized equipment.

One shop purchased its first piece of NC equipment in 1957. Others bought their first NC machinery in the 1960's, and still others purchased their first computerized equipment in the 1970's. All of the shops in the study had had NC or CNC for at least 4 years. One of the shops had gone through bankruptcy proceedings a decade ago, and had purchased their first NC machine while still in bankruptcy.

Products: All seven shops were job shops, working under contract to other companies, with no product of their own. Work is obtained by bidding on contracts let by client firms. All shops performed precision metalworking, sometimes requiring work at very close tolerances. The chief client industries of the shops, taken as a group, were aerospace and defense, with significant amounts of production for the electronics industry as well. None of the shops was dependent on a single major client.

Batch Size: Parts were made by the shops in batches ranging from one to several hundred. Average batch size at most of the shops was in the neighborhood of 200. There was, however, considerable variation in batch size. One shop, for example, had taken on what was for them a very large production run which would tie up one NC machining center for the entire year.

Labor Relations: None of the shops included in the study was unionized; this is typical of small metalworking shops. Employees thus had no mechanism for exerting collective influence on work organization, employment practices, the implementation of new technology, or other managerial decisions which affect the work environment.

Turnover: Employee turnover rates varied, but at least three shops had extremely low turnover, with perhaps one or two employees leaving per year ("And most of them come back," said the president of Alpha Metalworking). One shop reported high turnover--equal to about five times the size of the work force in 10 years. At yet another shop, there had been a period of high turnover about 5 years ago, followed by relative stability. Turnover at all the shops is currently low, reflecting in part a weak economy.

V. THE MACHINING PROCESS

Generally, in small machine shops without computerized machine tools, the production process takes place in the following sequence:

1. The shopowner will bid on machining jobs suitable to the type of equipment and the skill of the workers in the shop. If the bid is accepted, the owner uses an estimate of the time required to produce the part in order to schedule its travel through the shop.

2. The machinist who will make the part is given a blueprint of the part, perhaps accompanied by a process sheet that outlines in general terms the procedures to make the part.

3. Working from the blueprint, the machinist calculates the path that the cutting tools should take as they remove metal during the machining process. Planning the manufacture of the part also involves selecting the proper cutting tools for the operation involved and choosing the initial rates at which the piece or tool will turn (the speed), the rate at which the tool or piece will move in the course of machining (the feed), and the depth of cut.

4. After planning the operation, the machinist sets the machine up to produce the part. This may involve the design and manufacture of the jigs and fixtures necessary to hold the piece during the machining operation. Jigs and fixtures also require machining, which is in some cases done by other machinists.

5. Finally, the part is produced by the machinist. In the course of machining the part, the machinist may modify the original plan based on feedback from the actual experience of cutting the metal. The vibration of the part and of the machine tool during the cutting process, the color of the part itself and of the metal cut away by the cutting tool, the sound of the cutting process, and the feel of resistance against the handle which the machinist turns as the piece and the cutting tool meet all provide information which may cause the machinist to modify the cutting procedure originally planned.

To become a highly skilled machinist requires years of experience with a variety of machine tools. The most highly skilled machinists, toolmakers, are accomplished at running the major types of machine tools, at planning the production of a piece, at building the fixtures necessary for production and then setting up the job, and at sharpening cutting tools. All-around (or Class A) machinists are equally accomplished at operating machine tools but do less bench work, especially the fabrication of jigs and fixtures. Class B machinists generally know one machine well, but are not capable of running a variety of machines effectively. Machine operators run the machines to produce the finished pieces but do not plan or set up the work that they execute. The exact definitions of each of these occupational titles varies according to the context in which they are used; those above are the broad definitions used for the purposes of this study.

The Automation of Machining

Numerically controlled machine tools substitute an electromechanical control system for human control. The process by which an NC machine tool cuts metal is identical to that by which a manually operated machine tool performs the same task. In the case of NC, however, a preprogrammed code directs the machine operation, while on a manually operated machine an experienced human operator executes the planned cuts. On an NC machine, a parts programmer determines beforehand the exact order of all machine operations and then translates this information, often with the aid of a computer, into a machine-readable code. As the program is read by the NC machine's control system, the machine's operations are guided by servo-motors which take over the function of hand-cranking or manually controlled motors on a conventional machine.

Since the metal cutting process itself is identical on both manual and NC machine tools, part of the planning that takes place before the machine ever cuts metal is similar. The sorts of calculations and the type of information--such as the character of the metal and the range of cutting tools available--required to do this sort of advanced planning are identical for conventional and for NC machine tools, although there are now programming systems on the market that automate some planning functions involved in the production of NC-readable tapes. A chief difference between manual and NC machining processes, however, lies in the way in which the initial cutting procedure is modified based on feedback from the cutting process itself. With conventional equipment, the machinist, who is standing over the piece as it is cut, responds to cues from the machine and the workpiece and modifies the machining process immediately on the basis of the cues. On NC machinery, modifications can also be made based on the observations of the machinist, but the human operator is generally more distant from the cutting process. Because of the high speeds at which NC machine tools operate, the work area is generally sprayed with coolant and, in the case of larger machine tools, glass doors separate the operator and the piece.

Because of the type of control system used on NC equipment, the operator cannot respond directly to problems or deviations which arise in the course of production, except by altering the feeds and speeds of the machine. Any other adjustments to the program must be made by editing the control tape. On the older generation of NC machinery, tape editing requires the removal and recoding of the tape, a function generally performed off the shop floor. The development of CNC technology, however, makes it possible to edit a program without remaking the entire tape. CNC machine tools have a minicomputer as part of their control system, allowing editing of the program at the machine itself. In the shops visited for this study, it was the general practice, when a program was prepared for a CNC machine tool, to load the taped program into the memory of the minicomputer. If any editing was done on the shop floor using the keyboard of the CNC control, that editing did not modify the program on the original tape. Shop managers then had the option of incorporating into the original program changes made on the shop floor, but could also choose not to retain such editing, since the original tape was not changed in the process of editing at the machine. CNC offers many conveniences, even for shops that do not allow machine operators to make any significant alterations to parts programs, because minor changes like adjustments for tool wear can be made on the spot rather than requiring a trip to the front office. Most shopowners interviewed expressed a preference for CNC over NC control systems.

Direct Numerical Control (DNC) links a computerized programming system directly to NC and CNC machine controls on the shop floor. With DNC, the program which controls the machine's movements travels over cables linked to the machines on the floor, eliminating the need to walk a program back and forth from the programmer's computer to the shop floor. Generally, DNC is thought to be the province of the largest manufacturing establishments; in this study's sample, however, two firms were close to implementing DNC. In one shop, the smallest of the group, the programming system and the wiring were in place--all that remained was to connect the CNC controls to the wires hanging from the shop's ceiling.

VI. MOTIVATIONS FOR PURCHASING NC: TECHNICAL AND SOCIAL

Small job shops survive and grow by successfully bidding on contracts let out by other companies. In order to attract and retain contracts, job shops must be able to ensure low cost, quality, and on-time delivery. The relative importance of each of these may vary depending on the particular job, but in general all are important to the continued operation of a job shop. As mentioned above, job shops are often awarded repeat contracts, with particular parts reordered every month or every year, making a good track record particularly important.

Costs can be reduced by reducing any of the following: running time of the part, time and materials consumed in planning and setup, the time the part spends in the shop, cost of capital equipment, downtime of equipment, cost of labor, and amount of scrap and rejected parts generated in the machining process. Quality of the product depends on the capacity of the machine to achieve close tolerances where necessary, on the abilities of the operator and of the programmer or planner, on the repeatability of the machining operation, and on the alertness of inspectors. On-time delivery is made more likely by increasing the predictability of and control over operations. The use of NC equipment affects many of these variables.

When shopowners talked about their motivations for acquiring NC equipment and the advantages they believed accompanied the introduction of computer-controlled machinery, these fell into two broad categories: advantages which were chiefly technical in nature, and those that concerned the social and organizational composition of the shop.

Technical Advantages of NC

With a computerized control system, it is possible to make with precision a class of complex parts that would be impossible to make on conventional machinery. Parts with compound curves that would defy a human operator's ability to control the movement of the piece are feasible with NC systems. The development of NC has had a particularly important effect in aerospace production, where it has allowed design changes that would not have been possible to execute on manual machinery. NC has also brought the cost of producing certain complex parts to within an acceptable range, making affordable the production of parts that would have been feasible--but prohibitively expensive--to produce manually.

NC programs, once they have been fully tested on the shop floor, have an inherent repeatability that many managers cited as an advantage. One vice president spoke with satisfaction of the ability to reduce "random human error" through the use of NC technology. While an NC control does not improve the ability of a particular machine to hold close tolerances during the machining process--that is, it does not increase the intrinsic accuracy of the machine--it does minimize the variation from one piece to the next. As a result, the owners of several shops said that they were able to phase out their previous practice of inspecting 100 percent of finished parts.

The use of NC machinery can speed the flow of production under most conditions. Because all the operations are preplanned and fewer setups are required, an NC machine spends more of its time cutting metal than a conventional machine. Moreover, NC machines are generally sturdier and built to operate at higher speeds than conventional machinery. For single parts or extremely small batch sizes, the time required to write a computer program may not be offset by the machining time saved, but for larger runs the total time from programming to finished product could be substantially less than that required for conventional production. Furthermore, for shopowners who tend to get repeat orders for the same part over a period of months or years, the ability to pull a stored program off the shelf and quickly set it up on a machine has the effect of speeding production significantly.

The capabilities of NC machine tools are such that less setup is required to produce a part on an NC machine than on a conventional machine. Much of the investment in jigs and fixtures is eliminated in an NC shop, with several consequences. First, the cost of preliminaries like the building of fixtures is substantially reduced, replaced by the capabilities of an expensive machine. This can have substantial advantages for some customers, particularly those who are trying out new design ideas. As the president of one shop pointed out, "You don't have the investment in tooling, you don't have the investment in the engineering of the tool." Second, the time that construction of fixtures usually takes is reduced or eliminated with NC. Finally, the use of NC machinery reduces the number of highly skilled toolmakers required for the building of fixtures, thus reducing the shop's overall requirements for highly skilled labor.

The Social Dimension of NC

When managers were asked why they had decided to acquire NC machinery, social and organizational issues were prominent among their motivations. Two particular aspects of NC--the fact that it allows the shop to operate with, on average, a less skilled work force, and the fact that it allows a more centralized control of production--were repeatedly stressed by shopowners.

Effect of NC on Skill Requirements

Ability to Employ Less-Skilled Workers: For three of the seven shopowners interviewed, the difficulty of finding the sort of workers they wanted was an acute and pressing problem. One of the chief motivations for acquiring NC equipment was, for these owners, the fact that NC allowed them to "get by" with less-skilled workers. The comments of one shop president are typical:

> [At the time we got our first NC machine] we figured if we didn't get into NC quickly we might as well go out of business. The biggest advantage was the labor help wasn't that great, and by going into NC we could put a less experienced man on and get a better result out of the product.

Even managers for whom the replacement of human skills was not the primary motivator expressed the conviction that NC equipment required far less skill to operate adequately than did conventional machinery. For those shopowners who felt themselves particularly affected by what they saw as a shortage of skilled machinists in the labor force, problems created by the hiring of relatively inexperienced employees precipitated their leap into NC technology. One vice president was so eager to mention that it was the lack of skilled labor that had pushed his company to acquire NC that the interviewers scarcely had their coats off before he had volunteered the information.

One point of universal agreement, set forward by shopowners and skilled workers alike, was that highly skilled machinists were a dying breed, and that current methods of training workers were not producing a new generation of craftspeople capable of replacing highly skilled toolmakers who were nearing retirement. The shopowners interviewed agreed that the deployment of NC machine tools was not in itself a "cure-all," as one owner put it, for the loss of the most highly skilled workers, but everyone believed that the use of NC provided a measure of relief for shops where owners' reliance on skilled labor was creating what management saw as a problem. The president of Gamma Manufacturing, himself a journeyman metal fabricator, described his perception of the change in metal fabricating.

> When I started in this business we used to work with hammers and chisels and height gauges and you had to do all the layout on the level and cut it out. As far as the degree of craftsmanship, the craftsmen that I served my apprenticeship under no longer exist. To find a guy who can do it by hand, you have to go back and find a guy that's close to 50 years old...[With NC equipment] we can actually put somebody on that machine who doesn't have any ability at all.

Owners' opinions about the amount of time necessary to minimally train a new NC operator with some mechanical ability but no machining experience ranged from a few hours to a few days. None of the owners interviewed believed that a new employee could be nearly as productive as an experienced machinist, yet they said that a new employee running an NC machine could be far more productive than a new employee in a conventional shop.

The skill shortage as a driver for increased automation is a frequent theme in the literature. A recent report from the National Research Council, The Competitive Status of the U.S. Machine Tool Industry, is typical. The report estimates the average age of machinists to be 58 and quotes a 1980 Defense Science Board Study that projects a shortfall of 250,000 skilled machinists by the mid-1980's. Speaking of the machine tool industry, an industry closely related to the small shops in this study, the NRC report states that "the general manpower picture...[is] one of an increasingly older workforce, among whom the maintenance of a core of adequate skills in sufficient numbers is increasingly uncertain."[4] The report continues by saying that "[T]he declining number of skilled craftsmenlike workers is a force pushing for new machine tools with greater simplicity of operation and control."[5]

The decision to acquire NC equipment, then, in addition to whatever technical advantages computerized control systems may present, has a social and organizational dimension. Owners' statements about their purchase decisions reveal the introduction of NC systems as in part a strategy designed to minimize or eliminate dependence on a group of workers with indispensable skills.

Although most owners are fully aware of the limitations on the extent to which NC technology allows them to reduce skill requirements in the shop as a whole, it is nevertheless true that the use of NC machines permits owners to change substantially their hiring and training practices. The statement of one machine shop president illustrates the magnitude of the change:

> The National Tooling and Machining Association lobbies for funds for training for skilled workers. We don't have that problem. We train our own. We have found that the one thing that NC equipment and CNC equipment has done is basically that it has transferred the skills to some extent from the person to the machine. So we now have been able to take people who have native mechanical ability who have never seen the inside of a machine shop before, train them, and they are excellent operators...For example, we had young men out there--one was an automobile mechanic, one was a carpenter--but they had native mechanical ability and they could run [NC], and they didn't have to be a toolmaker or a diemaker, which for years was a problem we had in this industry. And for those people who have not taken advantage of the technological changes, who still run the old style shop where you're dependent upon tool-and-diemakers, they are hurting, because there aren't any tool-and-diemakers being trained by anybody to speak of.

For one shopowner, the only one interviewed who did not have an extensive metalworking background, NC made shopfloor operations more accessible.

> My background is not in machining, but I'm able to run the whole operation. And physically run the machines and all, and do jobs that it would have been pretty prohibitive [for me to attempt on conventional equipment]. I can take an apprentice and put him on what would almost be the most complex job you could handle, and he can operate it with minimal instruction--proper supervision, but minimal instruction.

The same owner, after describing the good performance of an inexperienced employee whom he had trained himself on NC, spoke about firing almost his entire work force and starting over.

> I'm to a point where I might be trimming the operation down to almost myself and someone else and training people myself, my way. Sometimes too much knowledge that some people have is dangerous.

A move of this sort would be unthinkable in a conventional machine shop, but is at least conceivable in an operation built around NC equipment. This owner, in a shop with only six shop floor employees, also showed a fascination with the concept of the automatic factory, and said that he was determined to automate his business as fully as financially possible in order to increase his ability to control the operation personally.

Other studies have emphasized that there is a decrease in the skill requirement for machinists with the introduction of NC, although not as much of a decrease as shopowners had expected. For example, a study of 24 manufacturing firms, "Numerically Controlled Machine Tools and Group Technology: A Study of U.S. Experience," conducted by Robert Lund of the Center for Policy Alternatives at the Massachusetts Institute of Technology, concluded that:

> It has been widely claimed that NC builds skill into the machine and thus requires less skill on the part of the operator. What this study indicates, however, is a growing respect for the skills that NC demands and a recognition that, although the operator does not need all the skills that are required to operate conventional machinery, a high level of mental alertness and the ability to react quickly in crises are required. On the other hand, although these skills require a great deal of natural aptitude, the time required to train an NC operator is substantially shorter than that for conventional operator training.(6)

Increased Leverage with Skilled Workers: Contributing to shopowners' motivation to acquire NC machinery was an acute sense, exacerbated by their difficulties finding skilled labor, of dependence on an independent-minded group of highly skilled workers. This dependence created both a fear of losing valuable employees to other shops and a sense on management's part that they had insufficient control of production schedules and work methods. Small shopowners have a strong ethos about exercising close control over all aspects of their investment. For these employers, NC promised increased leverage in dealing with a highly skilled work force. The president of Alpha Metalworking, where the first NC machine had been introduced in 1974, describes the changes in his shop as increasing numbers of NC machines were brought in:

> Five, six years ago we were very dependent upon skilled labor, to the point where I spent half my life on my hands and knees begging somebody to stay and do something. And they tended to be prima donnas: "I don't work Saturdays" and "I don't work nights". And this is one of the motivating factors in bringing in NC equipment. That reduced our dependency on skilled labor. Not that we went out and fired all our skilled labor--we didn't. We just taught them to run the machines. Now I just don't have the same problem; if the guy says, "I can't stay tonight", that's all right. Some other operator will run the same machine and do it equally as well.

Another president also put his decision to invest heavily in NC equipment into a social context when he related it to his ability to survive the departure of skilled employees.

> These days you cannot even buy loyalty and dedication...That's where CNC plays a big role...all of the knowledge, basically, except for minor things, is in the computers, in the tapes. So if anybody leaves, they're taking nothing more than a few hours of experience on the job. With the conventional equipment, sometimes you lose a key person and you really have a problem.

The Centralizaton of Control

Owners of small, highly automated machine shops believed that NC had given them more control over the operation of their businesses. All owners interviewed stressed the crucial contribution that programmable automation had made to their ability to predict accurately the cost and timing of shop floor production. In addition, the ability of owners to establish a programming department and to employ less experienced operators had the effect of centralizing the planning of work operations themselves. Combined, the ability to determine scheduling and to specify the exact procedures for the execution of work make possible a significant increase in the amount of centralized authority present in small machine shops. NC equipment, owners say, dramatically improves their ability to schedule jobs--and this improved predictability of operations translates into more confident estimates, better routing of parts through the shop, and more accurate estimates of the completion time for jobs.

Estimating: Accurate estimation of the cost of production is key to successful bidding on jobs. If an estimate is too high, the shop risks losing the contract to a lower bidder. If the estimate is too low, the shop's profit margin may shrink or disappear. To increase the accuracy of estimates it is necessary to predict more precisely the cost and running time of a given job. To the extent that NC standardizes the running time for machining work, it therefore improves a manager's ability to make a closer estimate of the real costs of production. One owner of a small job shop wrote job estimates by actually writing the program for the particular part, feeding that program through the in-house minicomputer, and basing his estimates on the computer-generated running times.

Intensive Use of Equipment: Several owners stressed the changes that NC, simply because of the high cost of the machinery, had brought about in their attitudes toward capital investment. "You have to get used to being in debt all the time," said the owner of one shop with 21 NC and CNC machines. He went on to characterize the changes in the following way:

> One NC machine costs two and one-half times what our entire shop cost me when I started in 1969. What has happened is that it's switched from a labor-intensive business to a capital-intensive business, and it's happened very fast.

In a shop with NC equipment, careful scheduling is important not only because on-time delivery affects the shop's ability to win future contracts, but also because the cost of an idle machine is greater for more expensive machinery. Furthermore, as machining becomes more capital intensive, there is more pressure on machinists to maximize the amount of their workday spent actually cutting chips. Nevertheless, only one of the shops visited was running a second shift on their NC machines, with the result that there was considerable idle time simply as a consequence of prevailing economic conditions and the resulting dip in orders.

Delivery Time: Control over the scheduling of production enables managers to predict (and in some cases to influence) running time, thereby increasing the chances of prompt delivery of the product. Managers interviewed emphasized repeatedly that one of the major benefits of NC equipment was the way in which NC standardized the running time of parts. The president of a shop with 75 employees said:

> (NC) gives you a tremendous competitive edge. When I think of how we used to make some of these parts and compare it to now, NC just does it infinitely faster and better. It gives you the ability to do a much better job of scheduling, because if an NC makes a part today and it takes 2 hours, and you put the same part program up next year, it's going to take 2 hours. But in the old shop, if you gave Joe Jones the job and it took him 2 hours, then you give it to Pete Smith, it might take him an hour, it might take him four, because everybody works different. So scheduling the work through the shop was a nightmare...because you said, it should take him a week to do it, but it might take two, and you never knew why. NC allows you to do a much better job of scheduling.

Another manager, echoing these sentiments, said:

> (With NC) it's much easier to control what's going on (in the shop). I can get more accurate deliveries because I'm not depending on an operator. I know that once a job is set up--and you have a fairly good idea of what setup times are involved--I know the machine is going to turn a part out every 5 minutes. So I'll base my delivery on the machine turning the part out every 10 minutes and I'm usually very safe.

The use of NC equipment to standardize the running time of parts traveling through the shop is confirmed in a Harvard Business School case study of the Thomas Manufacturing Company, a small manufacturer of electrical fittings. The owner reported that "the machines operated at programmed speeds whereas individual craftsmen varied their work rate..."[7]

Other unpredictable elements remain, however, in the process of producing the finished product. "The thing that takes longest on NC equipment is the setup," said one vice president. "If we're going to lose money on the job, in most cases it's not because we've underestimated the actual machining time, it's because we've underestimated the setup time and the debugging time on the program." For example, the part may take longer than estimated to orient and clamp. Once the part is properly set up, a different order of cutting operations may be necessary to hold tolerance. The actual operations may take the same time, but finding the optimum order can be difficult.

Control of Work Operations: NC technology, because it runs off a program which determines the exact path the cutting tools will take as they fashion the finished piece, creates the possibility of dictating even the most detailed operations from a central office. Without NC, although the general character of the approach to the job might have been planned in the engineering department, job shops with small lot sizes such as those studied would have given the individual machinist responsibility for deciding how to approach each piece. A programmer with a few years of machining experience describes the contrast between the old system and the way in which NC shops are generally run:

> Obviously, if you have a person who's going to be running a part on manual machines he'd be doing it one step at a time. He would have to be following through and figuring everything out and planning what was going to be done first or second. As soon as you get into the NC--actually CNC is mostly the case--it structures everything so the actual operator has a much less active role in how the part is actually made. In other words, we take the print and we bring it down into operations and then we program out the operations, so by the time the operator gets the program, he doesn't really have any choice.

Once this type of planning is removed from the shop floor, owners can exert a high degree of control over the work planning process and access to the computer tapes themselves. There was some variation among the shops studied with respect to the ability of NC operators to modify parts programs, although with very few exceptions machine operators had substantially less influence on the planning of work than they would have had with conventional equipment. The vice president of Alpha Metalworking, the shop where operators' ability to edit programs was most tightly controlled, described his position on the subject of shop floor programming and editing.

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> I believe in having control over every program and every part, because there's a lot involved--I know nowadays there's a lot of new equipment out on the markets that you can program right on the control or right on the machine, but that is a concept that I don't believe in for our situation. I think it's a good concept if you have a little model shop, and you have one man, he wants to make a part, and he programs it, but here we have a central room where all the tapes are controlled, all the programs are controlled, the libraries for the parts, you have to consider all the latest revision on drawings. We basically have to have quality control of the programming...You don't want everybody out on the floor doing their own thing.

The removal of control from the shop floor is a theme that is often repeated by small shop owners at trade association and technical meetings. At the 1983 meeting of the Numerical Control Society, for example, Joe Smallwood, owner of a thirty-person job shop with fourteen CNC machines, commented:

> The man who has the ability to think, plan, and do the job is too valuable to let run a machine tool. We're not doing machining on the machine tool anymore; the machine only executes what's on the tape. The man who made the tape, machined the parts...Anytime (today) that you have a man on the shop floor making a decision, you're in trouble. Ninety percent of the decisions made on the shop floor are wrong.(8)

Taken together with the increased predictability of the time required to make a part, control of the planning process has given NC shopowners substantially more opportunity to control all aspects of part production than their counterparts in shops with conventional equipment ever had.

The Decision to Purchase NC

None of the managers interviewed regretted the acquisition of NC machinery or said that they would do anything differently if given the opportunity. A few described minor initial problems having to do with the length of time that it took them to "travel along the learning curve", and one shop president complained of repeated problems in the late 1970's with unreliable electronic controls. On the whole, shopowners seemed unanimous in their satisfaction. The shops studied, however, are not representative of all small-shops in this respect, since the sample was chosen based on the unusually high concentration of NC and CNC equipment present in the shop. Presumably, owners who saw no benefit to be gained from NC equipment, or who had bad experiences with their first NC machines, would not have gone on to purchase more computerized machinery and therefore would not have appeared in our sample. In this sense, this study focuses on the "success stories" of NC in its application to small machine shops.

Even among the most cautious shopowners, there seems to have been little detailed comparison of the costs of NC investment with expected revenues. Although some owners had done careful comparison shopping when they went to look for a new machine, even the most deliberate purchasers among the shops studied had only a hazy idea of the relative costs and benefits of NC. A couple of managers said simply that as long as they were able to finance the purchase of new NC equipment, they would continue to acquire it. One owner said that he bought NC machinery because he "just had a feeling we had to get it". A similar sentiment is expressed by Mr. Thomas in the Harvard Business School case on the Thomas Manufacturing Company:

> We never did any follow-up studies, but my gut feeling is that the NC machines performed better than expected. Anyway, the machines were bought to keep up with sales demand. It was either machines or more skilled people, and we could not get the people.(9)

VII. NC ON THE SHOP FLOOR

The form of work organization in the shop does not inevitably flow from the NC or CNC machines themselves. Instead, the technology provides a framework within which a range of choices can be exercised. CNC, in particular, provides substantial flexibility, especially with respect to the question of where programming should take place. Thus the organizational changes which accompany the introduction of NC must be seen as the products of owners' decisions about how the shop will be run, not simply as the natural result of the introduction of NC.

What happens when a new technology is introduced on the shop floor, however, may be somewhat different from what was intended or expected when the new machinery was acquired. While evidence pointing to clear decreases in overall skill requirements and increases in the amount of centralized control was found in all seven shops visited, there were also clear limitations to these tendencies toward the reduction of skill and of individual autonomy on the shop floor. This section discusses the changes in the organization of the shop that accompanied the arrival of NC equipment, and then turns to a consideration of the limits to this organizational change.

Based on evidence from all seven firms studied, the introduction of programmable machine tools in small job shops seems to have been accompanied by an organizational reshuffling; most notably, an increasing amount of the planning of work was moved off the shop floor to a programming department. In a conventional job shop, the detailed planning of work procedure, cutter path, tooling, and so forth would have been done at the machine by the machinist assigned to execute the job. In the NC shops studied, this was not the case. With few exceptions, even the detailed planning of work, not just the overall routing of work through the shop, was done off the shop floor by a programmer.

The planning of work and its execution had become two organizationally separate functions.

While a conventional machinist might have distinguished to some extent between planning time and actual machining time in the sense that one took place with pencil and paper before the metal was ever cut, this distinction would probably seem artificial to the machinist because of the amount of redesign that might go on in the course of actually machining the part. In NC shops, the separation of designer and executor is accomplished by assigning the two functions to separate people and by physically removing much of the programming work from the shop floor.

The production process in an NC machine shop differs from the process in a conventional shop in the following ways:

1. The shopowner bids on jobs in a similar way, although the sorts of jobs bid on and the types of contracts let to a highly automated job shop may be different from those coming into a conventional shop.

2. The blueprint of the part and general process instructions are given to the programmer.

3. The programmer selects the cutting tools to be used, plans the path of the cutting tools, and chooses the feeds and speeds. The programmer works from a blueprint and in many cases also uses a computerized programming system that abbreviates the process of writing machine-readable code.

4. Once the program is written, the machine must be set up. NC equipment generally requires far less use of jigs and fixtures, because the capabilities of the machine replace the functions of many sorts of fixtures. On a conventional milling machine, for example, a fixture might have to be built to hold the part in a specific orientation to the cutter so that an angle or contour can be cut. The machine table can move in the X or Y direction, but movement of both axes simultaneously cannot be controlled. On an NC machine, the part can be clamped directly to the table and the contour or angle formed by programmed instructions to the machine. The setup operation may be done by any one of a variety of people, including the operator, a working foreman, or a setup person. A shop with many pieces of NC equipment would be likely to have fewer people doing setup because of the decreased setup requirements of NC.

5. The program written by the programmer is tested, or "proved out", at the machine. The proving out may be done by the programmer and the operator, the foreman and the operator, or the operator alone.

6. The program is modified, or edited, based on its performance during the proving-out run. This editing may be done at the machine if it is a CNC machine, or at a tape punch which is either at the machine or in the programming office in the case of NC. Programs which will run on CNC machines may also be edited in the programming office if that is the preferred procedure at the shop.

7. After the program has gone through its original editing and is running adequately, it can be further "optimized", generally by a machinist who is skilled in machining methods and able to spot possible shortcuts or improvements in the course of running the part.

8. During a production run, there may be unforeseen events--a flaw in a casting which is being cut or the breaking of a tool--which require the intervention of the operator. Like an operator of conventional machinery, an NC operator responds to cues from the machine as it cuts the metal and may intervene in the normal execution of the program if the operator judges it necessary. The cues available from an NC machine, however, are more limited than those from a conventional machine tool. All tactile forms of feedback are eliminated, but an experienced machinist will also be alert to the sound of the cutting process and the color of the metal as it is cut.(10)

There is considerable variation among shops and even within shops regarding who takes responsibility for a particular step in the production process. However, it is generally the case that a series of operations usually performed by one person in a shop with conventional equipment is now divided between two--the machinist and the programmer. To illustrate this general principle and to demonstrate the considerable variation among small job shops, a description of programming practice in five of the seven shops visited for this study is offered below. These five were selected to highlight the most interesting methods and the variation among them.

The Planning of Work: Portraits of Five Shops

Alpha Metalworking

At Alpha, the president, who had no experience as a machinist, and his partner, the vice president, ran the shop. The president handled business matters while the vice president, who had served an apprenticeship as a tool-and-diemaker more than 20 years ago, acted as manufacturing engineer. They employ two full-time programmers whose office lies between the front offices and the shop floor. One programmer, also a tool-and-diemaker, has been with the business since its beginning and has been promoted to his current position. He also continues to act as a general troubleshooter on the shop floor, which gives him even more frequent contact with all aspects of production than he might otherwise have. The other programmer began his career as an engineering student, and then decided to work as a machinist in order to improve his design abilities. He began programming in 1967 at another shop. The programmers, in addition to writing programs for the NC machines, do the general process planning for supplementary work on conventional machinery.

When a new job comes into the shop, it goes first to the vice president who evaluates it and hands it on with general instructions to a programmer. The programmer writes a program for the part, using an in-house minicomputer and the APT programming language, a relatively complex but highly versatile programming tool. The computer converts the APT program into machine-readable code, and the program is put on a tape. The tape is then carried onto the shop floor and loaded into the memory of the CNC control. If any editing is needed, it can be done at the machine using the computer keyboard on the machine control. Because the tape has been loaded into memory, editing done at the machine changes the program in memory but does not change the original tape.

When the program is being proved out on the shop floor, the operator and the programmer work together to test the new tape. Although this shop had a highly skilled work force, the machinists had received no formal training in programming and were not supposed to edit at the machine. Editing on the floor was generally done by the programmer, in consultation with the machinist. The machinist had no input into the writing of the original program, but could make suggestions if the original program could not be made to work.

At Alpha, machinists did their own setup. There was a separate fixture maker, who presumably also serviced the conventional machines in the shop. NC operators generally stayed on the same machine all the time, and a machine operator would stay with a particular job on that machine from the first proving out of a program to the end of the batch. The principal alterations that operators were allowed to make while the program was running were changes in the feeds and speeds at which the program ran.

Any editing done at the machine was reviewed later in the programming department to determine whether the editing should be incorporated into the tape itself so that those changes would remain for the next time the program was run. No one on the shop floor had access to the tapes for the purpose of altering them. The only exception was the night foreman, who had some knowledge of programming and would make changes only when absolutely necessary.

Gamma Manufacturing

Gamma, a sheet metal fabrication job shop, is owned by several partners, including the president and vice president. The president is a journeyman sheet metal fabricator who rose to the position of plant manager at another firm. He started Gamma Manufacturing 10 years ago, and has since been joined in the business by the vice president, a mechanical engineer. Gamma has recently merged with a small machine shop whose owners are now partners in the consolidated business. The two shops remain physically separate, however, and Gamma is distinct both from its partner shop and from other machine shops in the sample in that its principal business consists of the bending and stamping of sheet metal, rather than in the cutting of metal.

In the sheet metal shop at Gamma there are three NC punch presses, an NC laser cutter, and five NC press brakes, in addition to conventional metal fabricating equipment. The shop has one full-time programmer, the nephew of the president, who started work at the company when he was 16 and learned programming on the job. Since 1980, he has done his programming on a Webber "Prompt" system which includes a plotter that makes a drawing of the part based on the specifications entered into the system, and then generates a program from those specifications.

Programs for all the NC machinery except the press brakes are written in the programming and engineering office, which is located in an open area near the vice president's office and a few steps above the shop floor. The press brakes, which are comparatively simple to program, are programmed on the floor by the leader in the press brake area or by the press brake operator. The leader also does setup and coordination of work in his area. Operators in other areas are allowed to edit on the floor, the president said, but "[Our programmer] gets it right 99.5 percent of the time." Big changes in a program are supposed to be made in the office. Any editing done at the machine leaves unchanged the tape or the floppy disk on which the original program is stored.

The president and vice president at Gamma repeatedly stressed the importance of their company's commitment to training. The president was very critical of the education system out of which most of his employees and applicants came. On one recent occasion, when he was screening 40 high school graduates for possible employment at Gamma, he had found that only 7 of the 40 knew what the sum of 3/8 and 7/16 was. The company's commitment to training includes participation in a State-run apprenticeship program and a conviction that employees should rotate through jobs in the plant. The vice president mentioned that when he joined the company he worked first in the grinding area, and that the clerical workers in the office had all had experience running the machines on the shop floor. Workers at Gamma are rotated through jobs to the extent that their interest and the production constraints of the company permit. The president felt that the most versatile employee was the most valuable to the company, and he believed in paying wages based on knowledge. Employees were rotated not only among jobs on the shop floor, but also through the programming department, where they were trained by the full-time programmer and others in the engineering area. In this way, knowledge of the programming system gradually made its way onto the shop floor.

At Gamma, as at the other shops visited, managers stressed the productivity increases which computerized program-generating systems like "Prompt" brought to their programming operations. Before the shop acquired the new system, the president said,

> We used to spend all our time doing the mathematics of these parts, feeding them into the computer. I was doing 'em, [the vice president] was doing 'em, my brother was doing 'em, my nephew was doing 'em. We had about six people doing 'em. Right now ... we're doing roughly four times more business and two people take care of the whole problem, which has freed [the vice president] and I up to go increase the business.

In addition, the computerized programming system had the advantage, he said, of compensating for the weak math background of the high school graduates hired by the company. Without the system, this suggests, the sort of job rotation practiced by the company could not as easily include rotation through the programming department.

Epsilon Industries

A recent start-up and the smallest of the seven shops visited, Epsilon industries has existed since 1974, with most of its growth taking place after 1979. The company is owned by the president, whose original business partner, a machinist, has left the firm. The president learned the business, including the operation of machine tools, from his partner. In the small shop, which has only six shop floor employees, are four Bridgeport CNC milling machines and a lathe. All programs for the millers are written by the manufacturing engineer, who worked as a toolroom manager and as a tool-and-diemaker before he joined Epsilon 6 months ago. Programs for the lathe are written by the lathe operator, a machinist with 8 years of experience, most of it on conventional equipment. The lathe operator learned to program at his previous job and is now applying his knowledge of programming to his present machine.

Two months ago, the shop acquired a Bridgeport "Easy Cam" programming system which uses an in-house minicomputer. For the first few weeks, the manufacturing engineer had the system at his house, where he experimented with it and learned to use it as a programming tool. He excitedly showed us how simple it was to use.

> There's a whole lot of language you have to learn for the various commands that can be done with APT. But with this machine you don't have to learn any specific commands. It's very easy...it prompts you and it guides you through the session...Once you get conversant with how to use the controls of the processor, you don't even have to be an engineer to write programs. You don't have to know how to do advanced trig or any of that. And you probably could write programs without knowing about how to manufacture parts, either.

The system, he said, saved hours of calculation and reduced the danger of math errors that existed with hand calculation. Although manufacturing knowledge was not necessary in theory, writing optimal programs did, in fact, require an understanding of machining and of how to break jobs down into separate operations. Once the program is written, the system also includes a software package that transforms the code in the programming system into a code readable by the machine. So far, however, Bridgeport has not developed the software that would allow a program written on Easy Cam to be translated into the appropriate code for the Japanese lathe in the shop, so computer tapes can only be generated for the millers. The lathe operator may use Easy Cam for calculating the geometry of a part for which he's programming the lathe, but he must make the translation into machine-readable code himself.

When a job first comes into the shop, the manufacturing engineer looks at the blueprints, writes the program and the process sheets for the part, and designs the tooling and fixtures. He is out on the shop floor when the program is proved out, and may also run the machines at times when there is a rush job in the shop. On the floor, in addition to the lathe operator with 8 years of experience, there is also a machinist with 15 years of experience who performs much of the rest of the highly skilled work in the shop.

At Epsilon, the four milling machines were set up in a circle so that two machines could be run at one time by a single operator. The only other shop included in this study where one person was running two machines was the largest of the shops, with a shop floor labor force of more than 20 times the size of that at Epsilon.

A striking feature of this small shop was the presence of direct numerical control. DNC is a technology generally thought to be characteristic only of very large manufacturing operations. Here, the Easy Cam system was wired so that it could be connected directly to the machines on the shop floor. At the time of the visit, the wires were all in place and hung from the ceiling over the milling machines. Once the machines were wired into the programming system, they could be run off programs transmitted over the wires from the front office. Any editing could be done either directly at the machine, with changes sent back into the main computer, or at the Easy Cam keyboard, where they could be loaded directly into the machine. This eliminated the need to walk back and forth between the office and the shop floor.

Zeta Metal Products

By far the largest of the shops included in the study, and the shop with batch sizes which most closely approximate those in mass production situations, was Zeta Metal Products. Owned and run by two brothers whose father had founded the business, Zeta performs precision machining work primarily for the aerospace industry. Originally, the vice president and co-owner of the shop did all the programming. Now, the programming department has four employees: a very experienced all-around machinist who had at one time worked as a foreman and who had 16 years of programming experience; a former drafter who had been hired by Zeta to do programming work; a person with an electronics background who had also worked as a machinist; and a recent high school graduate, the daughter of the machinist-programmer, who had originally been hired to do clerical work in the programming office. The experienced machinist, in addition to heading up the programming department, worked as "Manager of NC Operations", and his nonprogramming responsibilities consumed about two-thirds of his working hours.

Before a programmer at Zeta writes a program, it is discussed with the chief programmer. Tooling, setup, and other matters are decided in advance. The head programmer told us that programming is relatively "cut and dried" and that machining experience is unnecessary for programmers. This statement is at odds with the statements of programmers in other shops visited for the study, and this difference of opinion is reflected in the fact that only at Zeta were there programmers (2 out of 4) without a shop background.

Zeta has used the APT programming language since 1972. Recently the shop has been looking for alternative languages because they find APT cumbersome, but their concern that a newer language might not be well documented and maintained in the future has kept the management from switching over to a new system. Like other programming departments, the one at Zeta uses an in-house minicomputer. Also like several other programming departments, Zeta had tried timesharing on an outside mainframe computer and found it was not cost effective. The programming department is located in a building a mile or two away from the plant in which the bulk of the NC equipment is located. At the predominantly-NC plant there is a computer room with a terminal and other equipment, from which it is possible to do most programming operations.

Once a program is written and taken to the machine, the programmer may work with the leader or the operator proving out the program. Editing is generally not done by the operator during the proving-out stage, and operators are not allowed to edit at the machine. Operators may change the feeds and speeds at the machine, although the vice president says that they are not encouraged to do so. Neither are they actively discouraged, however, because of the possibility of scrapping a part or causing a wreck. Any editing at the machine does not affect the floppy disk on which the program is stored, and stored programs are only edited in the programming department. Major changes in programs are also made off the floor by programmers. The leader is the only person on the floor who knows APT, and is the major conduit for communication with the programming department.

The operator is given a set of prints, a computerized readout of the program, and a computer-plotted drawing of the part. The operator changes tooling and loads the parts, although a setup person makes the original fixtures, if needed, for the part. The operator is present during the running time of the job. With lot sizes ranging up to a thousand, an individual job may run for a very long time. Ten very large CNC lathes are lined up in pairs along one side of the main plant at Zeta, and each pair of machines is run by one operator.

Eta Engineering

Eta Engineering was unique among the job shops in the study because it had both a production and a prototype department under the same roof. In the production area, lot sizes averaging 30 to 50 were the norm, while in the prototype department newly-designed one-of-a-kind or a few-of-a-kind parts were being produced. This juxtaposition within one firm of a production operation, centered around NC equipment, and a more traditional craft-based method of production where only two CNC machines were in use, provides a contrast between an older and a newer form of shop organization. The craft-based section primarily utilized conventional machine tools that ranged from small Bridgeport milling machines to a number of high-precision jig bores.

When a new job comes into the shop, a vice president breaks the job down into basic operations and orders the necessary stock. The job is then passed along to the full-time programmer in the NC area if it is a production job, and to the prototype department if the job is of that sort. For production jobs, the programmer gets a blueprint and a rough process sheet, and works out the program on a Numeridex programming system, which the company has had for less than a year. Eta used APT on a timesharing system for a time, but has since abandoned it. The present system was chosen partly for its accessibility to users, because no programming language is required for its use.

The programmer at Eta began work at the shop as a machinist about 5 years ago. He found running CNC equipment tedious, he said, and began reading programming manuals during the running time of his parts. He taught himself to program, and was eventually promoted into programming when an opening occurred. He now writes the vast majority of the programs in the shop, and also designs fixtures for parts.

Two others in the shop do significant amounts of programming, although about a half-dozen machinists in the shop have some familiarity with programming. In the prototype department, one machinist writes the programs necessary for prototype jobs, except for very complex programs which are written by the full-time programmer. Originally trained as an accountant, this machinist also worked as a millwright and machine repairer before his present work as a machinist. The other shop floor programmer writes programs for the lathes in the production area.

Of the 40 workers on the shop floor, 10 are toolmakers, another 15 or so are Class A machinists, 10 are Class B machinists, and 5 are operators. This shop had the most highly skilled work force of all the shops in the sample. All of the machinists except the operators do their own setup, and those who have sufficient skill also prove out the programs that will be run on their machines. The programmer is there to help those with less skill. Editing at the machine may be done by the operator, the leader in the NC area, or the programmer.

Interestingly, in this shop, with one of the most decentralized programming operations, the vice president indicated that he would soon be moving in the direction of Direct Numerical Control, which would enable most programming to be done centrally and would create direct interaction between the central computer and the machines on the shop floor. In a followup telephone call 2 months later, he reported that the wiring for DNC had been installed in some areas of the shop.

Observations About the Planning of Work

The evidence from these job shops and the two others visited suggests that the owners of small metalworking shops take advantage of the opportunity, created by the introduction of NC, to move the detailed planning of work off the shop floor and into a programming department. As a consequence of owners' decisions about how to implement NC, then, comes the development of a programming department and a new division of labor in the shop. While basic process planning would have been done centrally in a conventional machine shop, the detailed planning of the work task in an NC shop is also centralized. The constraints on a machinist's ability to modify the procedure for running the part based on the actual performance of the program on the shop floor are enforced by technical (the introduction of electronically-mediated controls) and organizational (the prohibition on editing and the establishment of a programming department) barriers.

The shops portrayed above exhibit, in varying forms, the trend toward the separation of planning and execution. Both the uniformity among shops and the striking variation they exhibit with respect to the organization of programming are of note. On the one hand, all shops had programming departments and full-time programmers, and had considerable control over operators' ability to edit taped programs. On the other hand, shops varied widely in the extent to which they allowed either programming or editing or both on the shop floor. From Alpha and Zeta, where no programming or editing by operators was permitted, to Epsilon and Eta, where some machines were regularly programmed from the shop floor, to Gamma, where employees were from time to time rotated through the programming department, it is possible to see the variety of ways the planning function in a small job shop may be organized.

The Execution of Planned Work

In trade journals and the business press, NC machinery is portrayed as operating smoothly and automatically, with minimal human intervention. As such, it is the centerpiece of the much-touted "automatic factory". The fact that NC codifies the planning function and makes it possible to move planning off the shop floor and into the engineering department is seen as a quantum leap in the trend toward increased managerial control and oversight. NC machinery is thought to enable managers, in the now-popular phrase, to "close the loop of managerial control".

The corollary to the proposition that production on NC machinery can be effectively planned and controlled from the front office is the assertion that the actual operation of the equipment is a straightforward and routine task which requires little skill. In keeping with its image as an automatic process, it is said that NC equipment can be operated by anyone who can follow minimal instructions. All that is required of an operator is to load parts at the appropriate time, and push the machine's buttons in the right sequence. The conviction that NC operation is unskilled work is reflected in written discussions of the application of NC, and even in the derogatory references made by highly skilled machinists to the "button-pushers" who run NC equipment.

What was found in the seven small job shops visited for this study was that the successful and productive operation of NC equipment was far from an automatic process. The planning of production could not be fully separated from the execution of the production plan because it was invariably necessary to modify the original plan, embodied in the computer program, based on its actual performance on the shop floor.11 Bugs in the program, conceptual flaws in the design of the original piece, and unforeseeable problems with the machine or with the metal being cut all require modification of the original production plan.

Programmers, even experienced ones, may not write an accurate program on the first attempt. Programming is a complex operation, and conceptual and typographical errors can slip in with relative ease. Furthermore, a programmer who has been off the shop floor for a time, or one who has never spent much time on the floor, may substitute second-hand knowledge from reference books for the immediate knowledge of someone who spends every day with the machine itself. One very experienced machinist who is now operating an NC machine observed,

> You have your program--the programmer puts into it the feeds and speeds and everything else. That's fine, but that's coming out of a book, which is where they figure what the feed should be. But you can't base every piece of material you've got on that. Some materials you have to go slower. The book says by right you should be going this fast, but you can't do that on all pieces. Because the book isn't always right. It's only reference.(12)

Another experienced machinist, who edited but did not write the programs that ran on his machine, when asked whether he had to do much editing on the programs written by the shop's programmer, replied that "I never take a tape straight out of [the office] and just throw it on the machine and go to it. Nine times out of ten it's wrong."[13]

Even the best programmers can't anticipate certain things that may happen during the cutting process: a broken tool, a flaw in a metal casting, the effects of temperature and machine wear. A wide variety of events are impossible to plan for. Because of this, operator intervention in the machining process is still vital to production. The machine operator is a crucial link in the process by which feedback from the performance of the machine is used to modify the program which instructs the machine. An inexperienced or inattentive operator can fail to intervene at important moments, with potentially serious consequences for part, machine, and even operator.

No doubt some operator intervention will be eliminated in the future through improvements in technology. It is important to remember, however, that NC already has 30 years of development behind it. In many of the shops visited for this study, the equipment was state of the art. Virtually all the owners and machinists interviewed pointed to the importance of human intervention in the class of work they were doing--the production of small volumes of complex precision parts. While unmanned machining centers are already on the market, there are many types of work for which they are not suitable.

By and large, the owners interviewed were well aware of the importance of having skilled workers on the shop floor. They tended not to be swayed by the claims prevalent in the trade press about the "automaticity" of the machinery. Perhaps this has something to do with the fact that in a small shop, even the president is not very far from the shop floor. For one thing, most of the presidents interviewed had machining experience; for another, any problems caused by inexperienced labor are not likely to escape the notice of management in such a small organization. One president, who said that for his shop the ideal NC operator would be a tool-and-diemaker with NC experience, criticized the employment practices of large manufacturers:

> In large companies, they buy an NC machine, and then in their infinite wisdom they go out and hire the lowest paid person they can find to run it, and they say 'boy, are we smart. Look at that, we've got a guy at $4 an hour.' Now all that guy can do is hit the stop and start button, and if something goes wrong, if the cutter isn't cutting right, he isn't going to know. He isn't going to know until he generates enough scrap that somebody else comes over and tells him that it's wrong. With a tool-and-diemaker on the machine we can hold closer tolerances because he knows if it's cutting right; he can do in-process inspection, he can adjust the part. In a lot of cases, especially for the type parts we make, the way you load the part in the machine is almost as important as actually cutting it...It's very short-sighted to take unskilled, lower-grade people and put them on the machine, yet a lot of companies do it.

The president of the sheet metal shop echoed his sentiments, pointing to the problems that can be caused by inexperienced workers and emphasizing that hiring low wage labor is a false economy.

> Can a guy with very little ability run one of these machines? Yes, he can. But in the end he's going to cost you more money than a highly trained guy will...When I pay a guy $10 an hour or $12 an hour I guarantee he's pulling twice as much work as the guy we're paying $4 an hour.

The president of another company also expressed the view that skilled workers were a distinct asset in an NC shop.

> The vast majority of our people are tool-and-diemakers, and they have been trained to run the machining centers. In our opinion that gives us the best of both worlds, because it's a fine piece of equipment with a lot of the skills that a toolmaker used to have, plus with the toolmaker running it we can do things on our machines that most people can't do...But we couldn't keep all these machines busy if we depended just on tool-and-diemakers--there aren't that many of them around.

In addition to the costs to the organization caused by scrap, failure to detect cutting problems, and even occasional outright damage to a machine, there are some less obvious costs that affect the efficiency of the operation. A problem with a machine, a tool, or a fixture that a highly skilled machinist might be able to diagnose and fix alone may, in the hands of a less skilled operator, require consultation with a supervisor, a toolmaker, or even the repair personnel of the machine's vendor. More skilled workers require far less supervision and consultation with others in the shop, and may in many cases be able to correct or even prevent a problem much more quickly than a less skilled operator. The programmer at a shop with a number of highly skilled employees described the difference between more skilled and less skilled workers:

> The experienced toolmakers know when a tool is cutting properly. If they have difficulty or if they find it's impossible to make the part within tolerance, they will know or will suggest what you could do to make the part in tolerance. Whereas the inexperienced person is likely to say, "I can't get this dimension," the toolmaker would say, "I can't get this dimension without boring a hole first." The inexperienced one will say, "there's something wrong with this fixture" and the toolmaker will say, "I'll have to put another hole in this fixture."

A toolmaker at another shop described the skilled worker's crucial role in planning and design.

> We're supposed to work in conjunction with qualified engineers. Nine times out of ten they'll draw something up and the toolmaker will tell them, "Aw, it ain't gonna work". And it doesn't. But that's through experience. And that's what my boss pays me for.

Given such compelling evidence that the operation of NC is not a fully automatic process, some questions arise about whether NC equipment and the way in which it is used might hinder intervention by the operator. The considerable extent to which an NC machine does in fact run itself may create a problem for the continuing alert intervention of the machinist. NC has eliminated some repetitive work from the process of machining, but it has also removed an important element of creative work and a significant amount of the machinist's control over the process. NC may free the machinist to perform other tasks, but these tasks must be done at the machine since the attention of the machinist to the NC machine continues to be needed. NC has thus substituted for repetitive manual work the potential boredom of standing by a machine all day waiting and watching for problems that may require intervention. A bored machinist, one owner complained, makes more scrap, yet the very fact that NC has eliminated a considerable amount of operator intervention may make it difficult for a machinist to remain attentive and engaged.

Another issue about operator intervention is how the skills necessary to run NC equipment are and will be developed. The majority of the managers and machinists interviewed believed that training on conventional equipment was an important prerequisite for effective performance on NC equipment. Many, although by no means all, of the NC operators at the shops visited had experience running conventional machinery. There was no way to know, from the answers given by managers and machinists, whether the principal drawback of learning machining only on NC equipment had to do simply with the technical qualities of NC as opposed to conventional (less flexible, less tactile, etc.) or whether it had to do with the way in which NC machinists are often trained (only on a single machine, not taught to plan work, setup, etc.). Will the practice of placing relatively inexperienced operators on an NC machine without periodic exposure to conventional machines hinder the development of the skills owners say are desirable?

VIII. WORKERS' REACTIONS TO NC

There was considerable variety in the attitudes toward NC expressed by workers. While the sample of workers interviewed was small and by no means random, the results suggest the sorts of factors which are likely to influence a worker's reaction to NC equipment. In interviews with 20 shop floor employees at the level of working foreman or hourly worker, the research team found that attitudes toward NC were affected by a worker's present job description, previous machining experience, personality, skill level, and age. The presence or absence of at least a few years of experience on conventional machines appeared to be particularly important, because it determined the kind of work which a machinist would regard as an alternative to NC work. As a very broad generalization, less experienced workers and workers who had most of their previous work experience on NC preferred NC, while workers with high levels of skill and extensive backgrounds on conventional equipment did not like NC machines unless they had become involved in programming. No firm conclusions about the effect of any of these factors on the outlook of machinists is possible from this small a sample; instead, the discussion below is meant to be suggestive of the range of reactions from shop floor employees, giving some of the flavor of rich and varied interviews.

One of the most frequent comments about working with NC equipment was that it was easier than working on conventional equipment. For some, this meant primarily less manual labor. Two of the oldest skilled workers interviewed said that they preferred NC, but only because their age made them interested in lighter work. If he were younger, one said, he would definitely prefer conventional equipment. A young machinist-programmer with considerable skill for his years liked NC because "I'm lazy," although he said he didn't mind working on conventional equipment when his job called for it.

Ease of operation also meant less mental challenge for NC operators. The machinists who said that NC made them think more than conventional equipment did were invariably involved in programming at some level, or had considerable responsibility for planning their work. Operators not involved in programming said that operating NC equipment did not tax them very much, at least once the program was proved out and running well. One working leader on a group of NC machines said, "Once it's going, you're a robot."

While ease of operation was an advantage for some, many workers--some of them the same ones who liked the ease of NC--complained of boredom on NC equipment. Large lot sizes and long running times for some parts created particular problems. Several workers said that they did not dislike NC machines per se, but that some parts were more interesting to run than others. One worker interviewed was, at the time of the interview, working on a part with a 7-hour running time; he said that basically he had to stand over the machine all day, watching to see that everything was all right. Even NC enthusiasts agreed that operating NC could be boring, and its detractors were vehement on this subject. Some machinists filled in the time reading the newspaper, reading programming manuals (even though reading was forbidden in most shops), or deburring the most recently finished piece. Those few operators who did some programming would often write their next program during the running time of the machine.

Several operators emphasized the importance of variety in their work--variety in the sorts of parts they were given to run, and variety in the machines they operated. Boredom seemed to be most acute among operators who had to run several hundred of the same part and who did not rotate among machines in the shop. When it was possible to have frequent change in what they were doing, most less skilled operators expressed contentment with their work.

Several toolmakers had strong words about the job of NC operator. One of the older workers, a man with more than 25 years of experience, told us that if it were not for his age, he would prefer running a conventional jig bore because:

> It keeps my mind going all the time. I'm a worker, I'm not a sitter. So I like to be kept busy. My day goes by faster; my mind is more active. You get to be, in my opinion, on an NC, a little weak-minded. When you have a job that lasts more than a half hour and you have the time in between that you deburr your piece and have time to spare, I think you become weak-minded. You're not using your mind to its full capacity. I mean, it's just like you being a secretary, and you go in and you're typing all day. But now if you had to be a receptionist, just go to sit there and wait for people to come up to you, and it's not a busy office....A lot of times you go into a place, you find a receptionist or a telephone operator reading a book. To them it's fine, if you like to read all day long, that's OK. But get a job in a library. Like I say, I like to have my hands moving. To keep my mind rolling around._ Other people are different. Other people like to sit down all day.

The two skilled workers who talked the longest about their sense of pride in their craft also had the greatest contempt for NC ("tape") machines and what they saw as the total absence of skill in the job of NC operator. One, who said he had taken his current job as an NC operator because "NC is the future whether I like it or not" and "it looks good on a resume" said of NC machines:

> They're junk as far as I'm concerned....Machines like this, they're production machines, that's it....But there's more job satisfaction doing a job on a manual lathe because, this, after it's programmed in, look, what am I doing, think, push the button. Like I tell people, you can take a chimpanzee, the light goes on, push a button....Some people I know, they love standing by a machine like this 10 hours a day. No problem. They get their paycheck, they go home. Me, I start walking back and forth like a rat in a cage.

The other, a toolmaker who was not running an NC machine, described how little skill he thought was required to run an NC machine, saying

> The women are running 'em. You know, the housewives. All they have to do is know how to press a green button, and when a little yellow light comes on, oh, the machine stopped, undo the two bolts, take it out, throw the machine off, put the next piece back in, put the two bolts down and press the green button and sit down and read the newspaper for a while. That's it. That's all it takes to know to run an NC machine....If I had to run one for any length of time I'd go crazy. I wouldn't do it. I'd quit. I might run one for one day, but I couldn't run one for one week. And you wouldn't find any toolmaker or Class A machinist my age that could, or would. That's an idiot machine. That's exactly what it's for. It was supposed to be made idiot proof.

The vice president of the shop with a prototype department found that his most skilled employees refused to run NC equipment. This forced him to run his NC machines with less-skilled workers at the controls.

> It's been very difficult to get our good toolmakers to run tape equipment--they just don't want to do it. When we bought that first CNC lathe, that was a prototype piece of equipment, and we sent our best toolmaker to school along with a guy that I had recently hired from another company who had run an NC lathe and is a good Class A machinist...they came back and the toolmaker didn't want to have anything to do with the machine.

The working leader in the NC area of the same shop said,

> (Our biggest current problem with NC is) finding people not only capable of operating them, but willing to operate them....You'll find somebody who can do it and then once he's learned it he'll get quickly bored of it and he'll want to do something else, so you end up spending most of your time just training somebody, and you can't really run a shop training everybody all the time.... Prototype seems to be the goal; if a person were in prototype, then they'd be happy to be a machinist. That's the impression I get from several guys. Once they are in prototype, it seems almost like security, boredom disappears, and also in a way you're not only making your own program....you'll be doing your own setups. In other words, prototype is everything all together, and so boredom is gone, whereas an NC machine....everything is specialties.

The skilled workers who said they liked NC equipment were generally those who had programming and supervisory responsibilities. A universal sentiment among them was that if they had to go back to simply being an operator, they would definitely prefer to operate conventional equipment. Highly skilled machinists were the most derogatory about NC. One machinist, who did the programming for his machine and one other in the shop, said that he preferred NC to conventional because programming is "a challenge," and expressed an interest in becoming a full-time programmer. Another had become so interested in programming that he had risen to become the chief programmer in his shop.

Programming is of interest to skilled machinists because it restores to their craft an important element of control over the job. The desire to do programming and the correlation between programming and work satisfaction for skilled workers is confirmed in a case study of a medium-size machine tool manufacturer in England. The plant employed 450 workers in May 1981. The author concludes:

> ...operator control of programming or editing in this firm offered no advantages whatsoever in terms of increasing bonus pay. Rather it seems that a highly skilled and intelligent workforce simply did not wish to hand over the control to which they are accustomed, and accordingly their personal preferences were expressed in terms of 'maintenance of self respect', 'using skills', and 'gaining work satisfaction'. According to one operator, CNC machines '...cut your arms off, make you blind, make you deaf, and cut off your sense of feel....These machines deskilled us--being involved in programming brings some interest back'. And in the words of another, '...we still use our skill, and still have our self respect....If they separated programming and operating I would seriously consider finding another occupation.'(14)

The machinist who described himself as a "caged rat" was doing all the programming for his machine and agreed that doing programming and other planning tasks helped alleviate the boredom, but said that nothing could change the fact that you still had to stand there while the machine was running.

> How could you make the job more interesting? Don't do 1,000 parts. With a machine like this, get a good operator who knows what he's doing, and you give him a chance to do a setup, and learn how to program the machine, so that he can look at the readout and he can understand what the machine is doing, not just stand here and just wait and then push the button and take the part out; that would help for a while.

This machinist had developed two "games" that helped somewhat to keep him occupied while the machine was running: the parts that he was making were designed to be cut to a tolerance of .001, but he would adjust his machine after every part so that the variation between parts was not more than .0001. "I know I can do it and I know the machine can do it," he said, "so why not?" He also kept track of tool wear on a scrap of paper taped to his machine.

With respect to health and safety issues, opinions were quite varied. The prevailing opinion seemed to be that NC machinery was safer for the operator, chiefly because the operator was more remote from the cutting action than with conventional machinery, but few statistics were available. In the case of larger machines, there is often a metal and glass door between the operator and the workpiece. The operator's hands are away from the piece while it is being cut, unlike conventional machining. On the other hand, NC machines often operate at much higher speeds than conventional machines, and the potential for an accident, especially during the proving-out stage, is significant. For example, an error in the program or in the setup of the piece could cause the cutter to collide with a clamp, possibly even knocking the piece loose or shattering the cutting tool. In this context, the operator's remoteness from the piece is not an advantage, because the lack of direct control and tactile feedback can contribute to an accident.

It was generally agreed that NC machines were cleaner than manual machines from the operator's point of view. This was partly because of the remoteness of the workpiece and partly because NC machines use oil or coolant to bathe the piece during the cutting process, which eliminates metal dust and flushes chips away. The effect on the noise level was unclear, but may have varied by type of machine.

Workers did not agree on whether running NC was more or less stressful than running conventional equipment. A few felt that running NC was less stressful, that it enabled them to relax and take it easy. Most reported some stress inherent in the job, and for many the amount of stress seemed to vary according to the type of task they were being asked to perform on NC machines.

One of the important sources of stress on NC machines comes from the complexity of the machine and the remote-control character of its operation. Several machinists reported that the most stressful part of running NC was the process of proving out new parts programs. When an untested program is put on a machine for the first time, the possibility of a machining accident is significantly higher than it is for proven tapes. On a complicated piece of equipment, with limited control over the movements of the machine, machinists reported feeling apprehensive.

> These NC machines--they're unpredictable. You don't know what it's going to do, the first time you run that program. You're always on edge until it's proved out.

Age was another factor affecting whether a machinist experienced stress on NC, according to a machinist in his late 50's. He believed that younger workers in his shop experienced less stress on NC equipment than he did. Things can happen very quickly on an NC machine, because of the speed at which it operates, and this machinist felt that he couldn't respond as quickly as a younger worker.

Also contributing to the level of stress in NC machining--as in conventional machining--is the value of the part being machined. If a part is made from an expensive alloy, or if it already has many hours of human and machine time embodied in it, the consequences of an error can be very serious. To the extent that NC machinists work on more valuable parts, and to the extent that a mistake on an NC machine is more likely to cause a part to be scrapped than an error on a conventional machine, this pressure will be greater for NC machinists.

For a group of operators in one shop, a principal source of stress was that they were running two NC machines at the same time. This sort of "doubling up," impossible on conventional machinery, increases the possibility of an accident and gives the operator two machines, not one, to watch over. For one operator, it was the double duty, not the use of NC machinery in and of itself, that created stress.

The issue of stress was touched on by Leslie Nulty, formerly on the staff of the International Association of Machinists (IAM), in "Case Studies of IAM Local Experiences with the Introduction of New Technologies." While the shops in this study were unionized, the introduction of CNC into a small specialty shop raises issues that are related to nonunion situations as well. Nulty maintains that:

> The high speeds of CNC machines (three to four times that of standard machines) require enormous concentration in a specialty operation like this, where expensive alloy castings are machined to fine specifications...(15)

The lack of preventive maintenance on the CNC machines in this shop created a situation in which machine parts or workpieces could fly off the machine. This hazardous condition and the increased level of concentration combined to increase the stress levels of operators.

Some workers expressed fascination with the NC machinery and its capabilities. This was independent of the content of their particular jobs but instead had to do with the complexity, speed, and repeatability of NC machinery. Computer-controlled machine tools were novel and impressive to them. They were a part of the future, an arrival from the computer age. A toolmaker now working as a programmer described his early interest in getting involved with CNC because "it's the second industrial revolution" and he wanted to be a part of it. Some workers greeted the new machines with enthusiasm because of their novelty, but others accepted them with resignation. "If you've got to make 1,000 parts or 10,000 parts, you've got to have a machine like this. There's no two ways about it...it's the wave of the future, whether I like it or not," said one skilled machinist.

Finally, highly skilled workers expressed deep concern about the implications of NC machinery for their craft.

> (Using conventional machinery) that's where you get to use your skills, your knowledge. You feel like you're doing something. When you take a raw piece of material and look at the blueprint, and whether it be 3 weeks, a month later, and that's a finished part, and you look at it and say, I made that. Tape machine didn't make that. I turned all those handles. I figured out how to do it. I ground the cutters to make the radiuses and the angles. I did that. And when you're finished with it, and somebody says, 'that's a nice job,' that's satisfaction. And the day goes by faster...because you're using your brain. You sit there on the tape machine, you can sit there and read a magazine or a newspaper. It don't matter. The machine's going to do it all for you.

Another machinist told us what he believed it took to be a good machinist:

> First of all you have to be able to read precision instruments... You have to be good with your hands....And in a way you have to be an artist. This is the end result, and you can tell a good machinist from a bad machinist like this. It's the work. You know, you can't fool anybody. There's no way you can fake anybody out. They'll catch you sooner or later.

In the shops visited, the most highly skilled workers, toolmakers, were spoken of with a respect that approached reverence. As one skilled machinist said of the toolmakers in his shop, "If God wants to make a part, he asks these guys." Shopowners seemed to hold toolmakers in equally high regard, and they believed that their skills were essential to the business. One president, whose toolmaker employees were all nearing retirement age, was asked what he would do when they were gone. "I don't like to think about that," he replied. Toolmakers, for their part, were unimpressed with the abilities of operators trained on NC equipment. One toolmaker said:

> If somebody tells you, go get me a #7 drill so I can tap a quarter-inch hole, the (NC) guy will look at you like you're nuts. What's that? What are you talking about? Tape machine guys don't know that--you get a guy on a manual machine, he knows. If anybody wants to know anything about how to make a part, you don't go to a tape machine; you go to a guy on a manual machine. He knows how to make that part.

This toolmaker believed that NC machines were hurting his trade, and that because they fragmented the craft they destroyed the sense of satisfaction that comes from producing a finished part. The best part of his job, he said, was:

> Pride in what I do. Because I know nobody can make anything any better than I can. If somebody wants something made, they come to me for it. It's job satisfaction. When you have job satisfaction, and you like what you're doing, you do a good job. It's not a drudge to come to work. It wouldn't be a drudge if, you know, I do 60 hours a week. If I hated my job I couldn't do 60 hours a week.

The concern for skill and pride in craftsmanship was very strong in most of the toolmakers and Class A machinists interviewed. They all believed that while an NC operator might develop enough skill to be a good operator, such a person would never approach the skill level of a person trained on a variety of conventional machines. Some expressed concern for the future of their trade, observing that there were no toolmakers being trained anymore. Also, while confident of their own ability to find employment anywhere at any time, they questioned whether NC operators were not far less mobile and would command lower wages, since they were "a dime a dozen."

IX. CONCLUSION

To better understand the effect of the adoption of NC machine tools in small job shops, site visits and interviews were conducted at seven metalworking job shops in

Connecticut. Some of the changes in the work environment that accompanied the introduction of NC were found to stem from the technical characteristics of the machines themselves. For example, the complexity and high operating speeds of NC machine tools contributed to the stress that some operators felt, especially when trying out new programs. However, the most striking work environment changes in job shops with NC equipment resulted from organizational changes made possible, but not dictated, by the use of NC equipment.

Shopowners were universally enthusiastic about NC equipment and its use. While no owner had made detailed comparisons of the costs and benefits of NC, most believed that the use of NC was what enabled them to stay in business, especially in a depressed economy. Owners cited several technical advantages of NC equipment:

- NC made it possible to produce certain complex parts that cannot be produced on conventional equipment. Because making these parts is now feasible, the shops' clients have begun to design parts that require NC equipment to produce. Owning NC equipment is thus crucial to the ability to win certain contracts.
- The fact that NC machines run off of stored programs gives NC production an inherent repeatability. The ability to reliably generate a series of identical parts can reduce scrap and eliminate the need for 100 percent inspection.
- Less setup is required for NC machines, which both shortens the production time for a part and reduces the number of hours that workers must devote to setup.
- For most parts, NC speeds the flow of production. Since NC machines require less setup and all operations are preprogrammed, an NC machine spends more time cutting metal than does a conventional machine. If an order is large enough that the time spent writing the program is more than offset by the reduced running time, production time is reduced.

In addition to these technical advantages, NC machines, because they run off of a preplanned program, offer shopowners a previously unavailable choice about who in the shop will do the detailed planning of work that will be executed by the machinist. The range of alternatives presented to the owner of an NC machine shop lies between these two alternatives:

1. Have the machinist who will operate the NC machine plan the cuts that will be made and write a program to execute these cuts. In a conventional job shop, this sort of planning is almost always done by the machinist who will produce the part. As a result, machinists with substantial experience on conventional machines have developed many of the skills needed to plan the production of a part. The development of computerized numerical control, which allows editing and programming at the machine itself, makes programming by the machinist even more feasible than it was previously.

2. Have the programming for NC machines done by a full-time programmer off the shop floor. This centralizes the planning of work, which was less centralized in conventional shops. More of the production operation can thus be controlled from the front office, and a new role in the shop, that of the programmer, is created.

Among the seven shops visited for this study, there was a striking variation in the organization of production and the locus of decisionmaking and planning activity. These variations resulted from factors such as the complexity of the machining operation being planned, the value of the part, the batch size to be produced, the operator's programming skills, and the personality of the owner. In spite of variations, however, the owners of all the shops had chosen to move in the direction of more centralized control over the production process. In addition to overall process planning and scheduling, which has always been the province of the owner in a small job shop, these small shops with NC equipment had also moved the detailed planning of work off the shop floor. The vast majority of the NC programming in some shops, and all of it in others, was done by a programmer rather than by machinists. Thus, the amount of autonomy which machine operators could exercise was substantially reduced, and the ability of owners to predict and control the operation of the shop was significantly enhanced.

There are technical reasons why, in some cases, it is more efficient to have programming take place off the shop floor. Some parts programs are very complex and could be written only by someone able to devote careful attention for several hours to the process of constructing the program. In other cases, it is more efficient for programming, and particularly editing, to take place on the shop floor. Because the machinist is the person closest to the cutting process itself, improvements can be incorporated more readily into the program.

The fact that machinists were not writing programs for their machines even in situations where it would have been technically advantageous points to the fact that the way in which NC machines affect the work environment is socially as well as technically determined. Two principal reasons why owners sought to expand and consolidate their control of shop operations emerged in interviews.

1. Although they recognized the value of skilled workers and knew that NC machines could not be run as productively by a less skilled work force, owners saw themselves as vulnerable to the independent-minded behavior of skilled workers. In situations where their skill is vital to production, highly skilled workers have considerable power to set the conditions of their work. The more indispensable the employee, the more leverage that person has in the employment relationship and the more damage is done to the shop by his departure. By centralizing control of shop operations and reducing skill requirements on the shop floor where possible, employers increase their relative power and make themselves less vulnerable to the claims of skilled workers.

2. Shopowners described their investment in NC equipment as motivated, at least in part, by the difficulty they had in finding skilled workers. Because NC equipment enabled them to operate productively with a less skilled work force, owners saw investment in NC as a technological solution to a social problem. Fundamentally, the owners of small job shops saw themselves as the passive recipients of whatever the labor market had to offer. Even those shopowners with a substantial commitment to training felt that this commitment was necessary because those who in their minds should have been doing the training--the vocational schools--had fallen down on the job.

NC and the Work Environment

By reorganizing production in such a way as to centralize control and reduce the overall skill requirements of the shop, owners have brought about changes in the work environment that substantially reduce the attractiveness of machining jobs, especially for skilled machinists. In addition to affecting workers on the shop floor, this also has the potential to affect productivity. There are costs to minimizing the input of the machinist running the machine tool. While reducing the possibilities for intervention aids in guaranteeing that a minimum standard of quality will be met, it also limits the ingenuity and skill that can be brought to bear in the production process. The input of the person closest to the production process is substantially reduced or even eliminated; when a skilled worker is operating the machine, the loss in terms of the quality of production could be sizable.

Another way in which the centralization of control, expressed most immediately in the removal of all planning work from the shop floor, may create problems for production is that machining work has been transformed in such a way as to be unattractive to the most skilled members of the work force. The usefulness of skill when running NC equipment was emphasized by most of the shopowners interviewed; yet, because the most challenging part of the work has been removed from the shop floor, the job has become less desirable from the point of view of a skilled worker. Furthermore, the boredom that sets in while doing a job that requires less intervention than is needed on conventional machinery makes it difficult for the machinist to continue to pay close attention to the cutting process, creating a problem because NC machining is not a fully automatic process.

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Prospects for the Work Environment

Based on many machinists' comments about problems associated with the lack of interesting and engaging work on NC equipment, it appears that fundamental improvements in the quality of the work environment in the small job shops studied would require restoring some of what has been removed from the machinist's job--individual autonomy, and the ability to plan and control the process of machining a part. In some cases, the barriers to shop floor programming are technical, but in other cases they are not. This is demonstrated by the fact that shop floor programming is in fact taking place in limited amounts under certain conditions in some of the seven shops studied. Some of the technical objections voiced by shopowners to the idea of initiating or broadening shop floor programming may have technical solutions. For example, owners showed concern for protecting the integrity of the program, since it is important that programs be documented and be protected from unauthorized changes. Yet this important requirement is not incompatible with allowing machinists to do some programming; it requires instead the establishment of procedures that allow changes made on the shop floor to be recorded and stored for later retrieval.

Many of the sorts of changes that would enhance the quality of the work environment were present in an embryonic form in one or more of the seven shops studied. These changes are clearly *technically* feasible, since they have already taken place in a very limited way. They may also in some cases be more productive as well.

Based on visits to the group of small job shops described above, the following four strategies to enhance the work environment appear feasible--from a technical point of view--and desirable from the point of view of workers on the shop floor.

- programming of machines by the operators of the machines, except in cases where there are compelling technical reasons against it.
- increased control over the editing of programs by machinists who are at the machine, watching the execution of the program.
- training in programming for machinists, including rotation of machinists through the shop's programming department.
- training in machining that includes substantial work on conventional machine tools and periodic rotation onto conventional machines.

If any or all of these strategies were adopted, the result would certainly be an improved work environment. The fact that each of these changes has been made in some limited way in at least one workplace suggests that under certain circumstances these changes can be beneficial to the company as well as to the work force. Yet, it is also true that after a certain point, increases in shop floor autonomy, with an eye to improving the work environment, come in conflict with the shopowner's chosen way of managing the business. At that point, further improvements in the work environment come at the expense of centralized control.

FOOTNOTES

1. "1976 American Machinist Inventory of Metalworking Equipment," *American Machinist*, Dec. 1976, p. SR-4. *American Machinist* uses SIC 359, Miscellanous Machinery (except electrical), as a proxy for job shops.

2. Detailed information regarding the application of numerical control since 1978 is available from the November 1983 publication of the thirteenth *American Machinist* magazine inventory of metalworking equipment.

3. "1976 American Machinist Inventory of Metalworking Equipment," p. SR-5, SR-6.

4. *The Competitive Status of the U.S. Machine Tool Industry* (Washington, D.C.: National Academy of Engineering, 1983), p. 24.

5. Ibid, p. 26. A skill shortage is not a mandate for automation, although the shopowners interviewed and much of the trade literature obviously perceive automation to be the answer. Other approaches to dealing with a shortfall of skilled workers include better training and more satisfactory incentives, financial and otherwise, for people to enter the occupation.

6. Robert T. Lund, Numerically Controlled Machine Tools and Group Technology: A Study of U.S. Experience (Cambridge: Center for Policy Alternatives, Massachusetts Institute of Technology, 1978), CPA-78-2, p. 54.

7. "Thomas Manufacturing Company" (Cambridge: Harvard Business School. 1980), 9-680-103, p. 2.

8. Bruce Vernyi, "Job Shops Need CNC to Meet Competition," *American Metal Market*, May 2, 1983, p. 14.

9. "Thomas Manufacturing Company," p. 2.

10. A number of advanced sensory controls that automatically respond to excess tool wear or breakage are now under development. These systems, generally called adaptive control, are designed to relieve the operator of responsibility for adjusting speeds and feeds. There are, however, important development problems. *Iron Age* magazine maintains that "although AC was widely hailed in the 1960's as the wave of the future, it has yet to deliver the expectations of efficiency and increased output." ("Does Adaptive Control Still Promise Improved Productivity," *Iron Age*, July 27, p. 57). Most current applications are limited to the aircraft and aerospace sectors where a high technology infrastructure is vital in utilizing the technology. Although adaptive control will undoubtedly be refined in the coming years, a near-term impact in small shops is unlikely.

11. Some new programming systems simulate the action of the cutter moving across the part to aid in detecting programming errors. These systems are very useful in uncovering gross mistakes, such as the cutter hitting a clamp, but critical nuances remain that can only be detected from the shop floor. Consider the

following example taken from one of the job shops visited for this study. A cyclindrical aluminum bar had the top face milled flat from end to end. After this, two holes were drilled whose center distance was a critical dimension. There was a great deal of difficulty in maintaining this tolerance until it was noticed that by performing the milling operation first, the heat of the rapid cutting caused the bar to expand. The holes were then drilled in this expanded state so when the metal cooled, the center tolerance was off. By reversing the order of operations, the problem was solved.

12. The "book" speeds for milling cutters can be accurate if cutting conditions are straightforward, but there are an extraordinary number of variables that influence the machining process. Consider the optimal cutting speed for an easy-to-machine aluminum alloy. This reference value may work well on a medium facing cut with a sturdy end mill on a well-supported part. But the same cutter speed could be disastrous for milling a deep inside pocket with thin walls while utilizing an extra-long cutter.

13. There have been few published studies that analyze the nature and quantity of errors in first-run part programs. One such study was done by Wean United, Inc., in their Youngstown, Ohio plant. In 1983, 1,848 new programs were run for 18 NC machines. A program with an error was defined as "one that required unprogrammed operator intervention." Based on this definition, 76.5 percent of these programs were error free. Of the 19 possible reasons for program changes, 8 are programmer controlled and 11 are not. The 3 most important problem areas, accounting for almost half of the total errors, were all programmmer controlled: dimensions, technique, and speeds and feeds.

    Upon closer examination, however, much of the high percentage of error-free programs was attributable to relatively straightforward NC machines. The relatively simple point-to-point drills were 91.8 percent error free, the somewhat more complicated horizontal lathes were 77.2 percent error free, and the complex multi-axis milling operations were only 25.3 percent error free. (Reference: Norman L. Flavell and Earl Kincaid, "'Oops,' Said the NC Programmer," American Machinist, June 1983, p. 135.)

14. Barry Wilkinson, The Shopfloor Politics of New Technology. (London: Heinemann Educational Books Ltd., 1983).

15. Leslie Nulty, "Case Studies of IAM Local Experiences with the Introduction of New Technologies," in Labor and Technology, Donald Kennedy, Charles Craypo, and Mary Lehman, eds. Department of Labor Studies, Pennsylvania State University, 1982.

TABLE 1

	ALPHA	BETA	GAMMA	DELTA	EPSILON	ZETA	ETA
Total Employees	75	19	74	16	10	200	48
Employees on Shop Floor	60	16	60	15	6	130	40
Annual Sales	$8.2M	$900,000	$4.5M	$600,000	$300,000	$25M	$2.7M
NC and CNC Machine Tools	21 NC and CNC	2 CNC lathes 1 CNC miller 16 NC millers	3 CNC punch presses 1 CNC laser cutter 5 CNC press brakes	6 CNC	4 CNC millers 1 CNC lathe	12 CNC lathes 2 CNC vertical millers 30 NC machines	21 NC and CNC machines more than half of these are CNC 2 CNC in prototype
Year Company Founded	1969	1940	1973	1972	1974	1945	1942
Year First NC or CNC Machine Tool Purchased	1974	1966	1976	1976	1979	1957	ca. 1966
Principal Client Industries	military aircraft medical	varied: electronics, hydraulics, etc.	mostly electronics	electronics aircraft	aircraft medical	aircraft, both military & commercial	electronics aircraft
Programming System	Digital "APT"	Genesis "Encode"	Webber "Prompt"	Webber "Prompt"	Bridgeport "Easy Cam"	Digital "APT"	General Numeric "Numeridex"
Age of Programming System	3-4 years	5 years	3 years	6 months	2 months	11 years	1 year
Lot Size Range*	10-150	25-1000	10-2500	100-5000	50-1000	1-1000	1-100
Average or Typical Lot Size*	50	250-500	200	250-500	250	100	50
Employment Level Over Time	steady growth	stable for 10 years, before that steady growth	steady growth	fluctuates, down from a peak of 19 in 1980	growth, recent layoffs	cyclical, twice as many employees in late 1960s, constant for last 7 years	stable
Size of Shop in Square Feet	13,000	10,000	30,000	8,000	2,500	66,000	28,000

*lot size figures are rough estimates only

GLOSSARY

COMPUTERIZED NUMERICAL CONTROL (CNC) - A numerical control system which uses its own stored-program computer to perform some, or all, of the basic numerical control functions in accordance with a control program stored in the computer.

DIRECT NUMERICAL CONTROL (DNC) - The operation of a number of machines directly from a single relatively large computer. Unlike CNC, in which a computer--usually a minicomputer or microcomputer--replaces hardwired electronic components, a DNC system normally supplements conventional electronics and automatically regulates the operation of a number of machines. There can be as many as several hundred machines involved in a DNC system. One of the advantages of a DNC system is the ability to centrally load and control parts programs.

FEED FUNCTION - The relative travel motion between the cutting tool and the workpiece. The movement is usually expressed in inches per minute (ipm) on a milling operation and as inches per revolution (ipr) on a lathe operation.

JIG BORER - A precision machine tool resembling a vertical milling machine, equipped with sensitive adjustments for the table and the position of the cutting tool: it is used especially for locating and drilling or boring holes in jigs, an operation requiring work at particularly close tolerances.

LATHE - A machine in which work is rotated about a horizontal axis while being held in a chuck, face plate or mandrel or between centers in headstock and tailstock. The work is shaped by a fixed cutting, boring, or drilling tool.

MACHINING CENTER - A new breed of NC machine tool that incorporates the functions of many machines into a single device, thereby reducing work handling. It is equipped with multiple tools to perform such operations as milling, drilling, boring, and tapping.

MILLING MACHINE - A machine tool on which the workpiece, secured to the machine table, is shaped by being fed against rotating milling cutters. Milling machines are made in vertical and horizontal versions.

NUMERICAL CONTROL (NC) - A system in which the movements of the cutting tool or workpiece are controlled by the direct insertion of numerical data, which may be stored on paper tape, magnetic tape, in the memory of a computerized control, or loaded from a central computer. The system automatically interprets at least some portion of these data, translating them into movements of the machine.

PRESS BRAKE - A press used to bend metal bars or sheets.

SPEED - Refers to the rotation of the machine spindle, measured in revolutions per minute (rpm). In the case of a lathe, this refers to the spindle that holds the workpiece; for a milling machine, it refers to the cutting tool.

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The Effects of Programmable Automation on the Work Environment: A Case Study of an Agricultural Implements Manufacturer

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I. INTRODUCTION

This case study investigates the effects on the work environment of the introduction of a wide variety of computerized systems by a midwestern manufacturer of agricultural and construction equipment. The company is regarded as one of the leading users of programmable automation in medium batch manufacturing. In one of its principal businesses, the manufacture of tractors, it has moved aggressively since the middle 1970's to install a very large number of new machines and systems that are dependent on computers and microelectronics. This study focuses on two plants that have been widely recognized as examples of the company's pioneering automation efforts: the components manufacturing plant and the nearby tractor assembly plant. These two factories alone contain a wide variety of programmable systems, from computer-aided design to robots.

While the applications are diverse, the common purpose uniting these technologies is the use of computers to collect, process, and transmit information. In some cases, computers dictate the operations of a single machine such as a robot or a numerically controlled machine tool. In other cases, computers link individual machines into manufacturing networks such as the Flexible Manufacturing System (FMS)--a combination of numerically controlled (NC) machine tools, automatic part transfer, and overall computer control. And in still other cases, computer-based management information systems give managers a previously-unavailable overview of the company's operations, whether in a small department or in manufacturing operations scattered across the globe.

After a brief description of the methods used by the research team in preparing this study, the company's current position in the agricultural implement industry will be reviewed. This is followed by a description of labor-management relations at the plant, with particular emphasis on the company's highly productive incentive wage system. Next, the company's purposes in introducing automation are discussed. The core of the case study is an examination of the work environment effects of three specific automated systems: a computerized labor reporting system in use at both locations, a material handling system in the tractor plant, and a flexible manufacturing system in the components plant. After this, the issues of health and safety and the concerns about displacement expressed by the company's workers will be reviewed. Finally, a conclusion sums up the major issues in the case.

In focusing on individual systems, it is easy to overlook one of the fundamental features of the advanced application of programmable automation: the way in which it can be used to tie together various aspects of production. Computer-integrated manufacturing is an apt term to describe this process. Computers may be used not only to run individual systems, but to coordinate the wide variety of functions which make up the overall production process. More and more, computers come to link "islands" of automation. This process can be seen at work in the company on which this case focuses. Thus individual systems must increasingly be viewed in the larger context of the company's overall strategy and objectives in introducing programmable automation.

From management's point of view, the introduction of such a substantial number of computerized systems has brought many benefits, not only in the two plants included in this study but in the company as a whole. In fact, the company's management repeatedly stressed that programmable automation has been vital for the company's success in an increasingly competitive industry. The technology has resulted in increased flexibility to respond to rapidly shifting market conditions, better product quality, and higher productivity. An important element of higher productivity has been the transformation of what management saw as a series of difficult-to-control, stop-and-go operations into a more tightly controlled, centrally directed "even flow" of parts reminiscent of operations in continuous process industries.

The central objective of this study is to investigate the impact of programmable automation on the work environment. This impact is not simply a function of the technical features of the equipment alone. The same technology can be used in a variety of ways and in different contexts, with a range of outcomes for the work environment. The character of the automated workplace is the result of the combined interaction of many factors: the technical capabilities of new machines and systems, the managerial philosophy and intent of the company in introducing new technology, the systems' actual shop floor performance, the form of work organization and the character of labor-management relations that set the context for the systems' use, and the attitudes of workers who operate the equipment on a day-to-day basis.

Despite the differences among various systems, some powerful overall themes emerged. These themes include:

- Greater interdependence among workers on the shop floor. The integration of machines into systems ties production workers more closely together. Moreover, the maintenance of these more complex and interrelated systems requires more cooperation between production and skilled workers as well as more collaboration among different skilled trades, such as electricians and machine repair.
- In some cases, production jobs become cleaner and less physically demanding, such as the FMS operator's job.

-- Less autonomy on the shop floor, a direct consequence of better managerial control. Management information systems, for example, give more visibility to operator activities (raising concerns among some operators about electronic monitoring) and facilitate enforcement of more standardized work practices. These systems can also limit the supervisors' range of choices in certain personnel and scheduling matters.

-- Boredom for some production workers, such as FMS operators, accompanied by more stress when intervention is required.

-- A perception by some workers that the use of several new systems has resulted in disorganization rather than efficiency. There were complaints that, at times, computerized systems made it more difficult to informally resolve problems that workers and supervisors had been able to deal with in the past.

-- A serious concern on the part of most workers about the number and type of jobs that will be available in the future. This concern is so widespread that it must be considered part of programmable automation's influence on the work environment.

There is little question that new computerized technologies are laying the basis for significant changes in the work environment. Some of these changes are the result of the design of the system, and others result from bugs that remain in the system. Still other effects may result from poor communication between management and workers concerning the system's capabilities. Overall, the researchers were struck by the fact that the debugging process is longer and more difficult, even in the hands of competent and experienced manufacturing people, than is generally acknowledged in the literature on computer automation. Moreover, even after debugging, some highly automated systems continue to operate in a way that is less than fully automatic, given problems of reliability in complex systems and the variability of the manufacturing process itself. Consequently, worker input remains indispensable to the day-to-day operation of production, although automated systems may have been designed to function with minimal human input. The level and nature of this intervention has an important influence on the work environment.

The reaction of workers to the introduction of programmable automation is shaped in fundamental ways by the company's incentive pay system. This system helps to create an extraordinarily highly motivated work force, and employees may use considerable ingenuity to keep machines running. Machine downtime is not welcomed by incentive workers, and most of the workers interviewed expressed intense frustration with automated systems that frequently broke down. In spite of this, workers expressed no opposition to programmable automation as such. Even those most sceptical and resistant to computerization viewed it as inevitable; others were more enthusiastic about the possibilities of programmable automation, but felt that it was being misused by the company. Still others were impressed with the systems which had been implemented and believed that the problems created in their work areas by programmable technologies would be resolved over time.

II. STUDY METHOD

This study is based on data gathered during a 6-day trip to the city in which the components plant and the nearby tractor assembly facility are located. Three days were spent touring the company's manufacturing facilities and conducting interviews with members of management. The balance of the visit was spent interviewing members of the local union.

The company was extremely cooperative, providing the research team with an excellent overview of plant operations and allowing the freedom to explore areas of particular interest in greater depth. The first 2 days were spent gaining a broad introduction to the components plant and the tractor assembly facility, and the third day was spent in followup investigation and interviews, particularly at the FMS. Interviews were conducted with company personnel ranging from the vice president for manufacturing to first-line supervisors in the tractor assembly plant. Also interviewed were the plant manager; the managers of manufacturing engineering, mechanical services, and process and tooling; several supervisory personnel; and the project manager and systems manager for the FMS--all at the components plant. Interviews were also conducted with the plant manager, manager of manufacturing engineering, and the controller at the tractor assembly plant. Interviews were open-ended, based on a prepared interview guide but tailored to the individual being interviewed, and lasted from 15 minutes to several hours. Tours and interviews were supplemented by several brief presentations by company personnel focusing on different aspects of automation at the company, by written materials supplied by the company, and by relevant articles and information obtained from other sources.

The worker interviews were arranged by the union, the United Automobile Workers, and conducted in the local union hall. The local union was very cooperative in arranging interviews and providing the space in which to conduct them. A semi-structured open format, similar to that used at the company but designed specifically for interviewing workers, was used to interview people both individually and in groups. The union was asked to arrange interviews with workers from the FMS area and those utilizing the company's labor reporting system. Also requested were interviews with workers from the components plant and the tractor works, skilled trades as well as production, of varying ages and seniority levels. A total of 18 workers were interviewed through the union. In this situation selection bias was unavoidable, but the workers interviewed appeared to represent a range of viewpoints with respect to computerized technology.

III. THE COMPANY'S POSITION IN THE AGRICULTURAL IMPLEMENTS INDUSTRY

The company and its subsidiaries manufacture, distribute, and finance the sale of a full range of farm equipment and a broad range of earthmoving and forestry equipment.[1] In 1982, the company had worldwide sales of over $4 billion; most were sales of agricultural equipment, predominantly large tractors and grain combines. The company has 11 factories in the United States as well as several abroad.

Since 1970, the company has spent over $2 billion on capital improvements; approximately half has gone into modernizing and expanding facilities in the state in which the plants studied are located, particularly in the manufacturing complex which includes the components plant and the tractor assembly plant.

An unusual combination of market forces prompted the capital improvement program begun by the company in 1971. In the late 1960's and early 1970's, worldwide demand for tractors fell, although the average size of tractors sold increased to match the growing average size of U.S. farms. Even with only one factory in the area--the present day components plant--the company found it had more than sufficient tractor building capacity. As a result, it began using the components plant to make transmissions, axles, hydraulic systems, and other components for sister factories. Thus, in 1971, the company had only a small amount of excess capacity, in contrast to its chief competitors.

In 1972, a number of short- and long-term factors combined to produce what would be an 8-year boom in farm equipment sales. Poor harvests in the Soviet Union, rising world population, and increasing demand for meat (and thus for animal feed) resulted in record grain prices and led American farmers to cultivate an additional 50 million acres--a land area equal in size to the entire state of Illinois plus half the state of Iowa.

Due to the farm boom and the successful introduction of a new line of tractors, the company soon faced excess demand and decided to expand its facilities; it built the tractor assembly plant and restructured the existing downtown site into a plant producing a variety of components.

The company has sustained most of the momentum it built up in the middle 1970's through the last 3 years, largely at the expense of its competitors. Choosing to continue its capital investment program and press its advantage over the competition, the company spent $1.3 billion on plant and equipment between 1978 and 1982. The company's agricultural equipment sales reached a peak of well over $4 billion in 1981. While sales dropped in 1982, the company's share of the domestic farm equipment market climbed, increasing significantly over its 1978 level. In 1983, with its tractor inventories at about 56 percent of annual demand rather than the desired 40 percent, the company's plants are operating at approximately 50 percent of capacity.

IV. LABOR-MANAGEMENT RELATIONS

The effects of programmable automation on the work environment are not determined simply by the features of the computerized machines and systems themselves. As mentioned above, the work environment in an automated plant is shaped by many additional factors, such as the system's actual performance and the managerial philosophy which guides its implementation and use. Labor-management relations is a very important factor contributing to the environment in an automated plant; in turn, it also affects workers' reactions to changes in the work environment. This includes both the overall climate of labor-management relations and the specific terms of employment under which the labor force of the company works. At the company under study, for example, even the workers who were most critical of the way in which the company was implementing new programmable technologies expressed a basic respect for the company and its management. It seems reasonable to speculate that if this basic respect were lacking, employees might have shown substantially more opposition to the introduction of these new systems.

Three features of labor-management relations are particularly relevant to an understanding of workers' reactions to the changes brought about by programmable automation. First, high unemployment prevailed at the company and throughout the agricultural implements industry at the time this study was conducted. Workers' concerns about the displacement effects of computerized technologies were likely heightened by their awareness of the number of people on layoff. Second, a long and bitter strike was in progress at one of the company's chief competitors at the time of the study. Finally, the company's incentive pay system gives about half of the company's hourly work force a substantial financial incentive to keep production flowing smoothly.

Layoffs at the Company

Over the last 4 years, employment at the company has fallen from 65,000 to 48,000 worldwide. In April 1983, when the research team visited, approximately 12,000 of the company's 28,000 U.S. production workers represented by the UAW were on layoff. In the city where the study was conducted 3,986 were on layoff. These workers have been on layoff an average of about 1 year, and about 900 have lost their seniority as a consequence of being on layoff for over 2 years.

The Strike at a Competing Company

Relations between the company and the UAW historically have been quite good--or at least more amicable than in most farm implement and industrial equipment firms. At the manufacturing site visited, both the management and the union described relations as better than average for the company as a whole. At the time of the research team's visit, however, workers at the company were working under an extension of an old contract, awaiting the settlement of a long and bitter strike at one of the company's competitors. The firm being struck generally sets the patterns for wage agreements in the industry, and both workers and management at the company being studied were aware that as soon as the strike was settled, they would enter into negotiations of their own contract. The highly-publicized strike, the longest ever waged at a national level by the UAW against a multiplant company, was an active topic of conversation at the UAW local where the interviews for this study were conducted, adding tension to the prenegotiations atmosphere.

The Incentive System

Since early in the century, the company's production workers have been compensated, at least in part, through incentive pay. Until 1955 a simple piece-rate system prevailed. In that year, the company introduced its present incentive pay system, which combines a standard base rate with a bonus for production above the standard rate. The company's desire to standardize production methods apparently motivated the change, which included the writing of detailed work instructions specifying the separate elements of each operation and the time each element should take. Workers are not permitted to follow other than the prescribed method without permission from management. The incentive system covers production workers--approximately half of those on the factory floor--who have some control over the pace of their jobs. Maintenance workers, for example, are not covered by the incentive system, since their jobs are not sufficiently routinized to be assigned accurate standard times.

The company's industrial engineering department designs its standard times so that an operator working at "incentive pace" earns about 130 percent of the "standard" base pay. The company aims to have production workers eligible for incentive pay about 85 percent of the time, the remaining 15 percent being set aside for "inherent delay." Inherent delay includes those parts of a job whose pace is out of the control of the worker (i.e., the pace depends entirely on a machine). During periods of inherent delay the worker is paid the standard rate. Workers are also paid the standard rate during downtime.

Incentive tasks on machine tools include such jobs as loading and fixturing. When individual machines (e.g., N.C. machine tools) operate for large portions of the time independent of the worker, the worker's incentive time can be boosted, for example, by giving that person responsibility for loading two or three machines.

The introduction of automation can influence incentive pay in two ways: first, by requiring determination of new incentive standards, and second, by changing the proportion of inherent delay and downtime in the job.

Each time new technology is introduced, the industrial engineering department must establish new incentive standards. If the workers are dissatisfied with the standards set, they may file a grievance. Workers only exercise this right about one percent of the time. Workers have never exercised their right to strike over incentive rates.

If the proportion of inherent delay or downtime increases with the introduction of new technology, workers' wages fall closer to the standard. Workers at the company claim downtime has increased to some extent as a result of automation, especially the introduction of the materials handling system.

The incentive system is reported by both workers and managers to be highly successful in boosting worker motivation and productivity. Evidence from interviews with workers suggests that an apparently capable and motivated work force has become, through the use of incentive pay, acutely conscious of any aspect of the production environment that hampers productivity, and extremely eager to avoid downtime and inefficiency. Workers told stories that suggested they would go to considerable lengths to become more productive on the job. One NC machine operator said that he had driven to Milwaukee during a 2-week shutdown of the plant. There he paid a visit to the company that manufactured the machine he ran, and asked for any information and training that would enable him to run his machine more effectively. One of the things he learned, he said, could enable him to run his machine when it developed problems while he was working overtime and no maintenance workers were available on that shift. Another worker said that he had taught himself to program using the computerized numerical control keyboard on the machine tool he ran, and that frequently he was able, with the tacit approval of the programmer, to rewrite the parts programs fed into his machine in order to make them operate more efficiently.

V. THE MOVE TO AUTOMATION

In the early 1970's, the company, a conservative manufacturer of agricultural equipment, began a transformation that would make some of its key plants into showcases of programmable automation. Faced with tremendous capacity restraints, the company began substantial investments to enlarge its productive capabilities. An important part of this investment concerned the introduction of new machines and systems based on computer technology.

"This was a once-in-a-lifetime opportunity to move into something new," according to the company's vice president for manufacturing. The bottom line was to use the technology to remain a low cost producer vis-a-vis its competitors.

The company was seeking a number of things from its heavy investment, such as:

-- Flexibility. The company wanted the maximum adaptability to changing market conditions.

-- Rapid response time. The desired flexibility had to be combined with rapid product development and a quick turn-around time. The company feels the product cycle has been cut from between 5 and 10 years to under 5.

-- Greater manufacturing efficiency. The company sought to go from the stop-and-go of batch manufacturing to the greater control and predictability of "flow through" processes.

-- Reductions in direct labor.

-- Better accountability and manageability. The company was seeking a better managerial handle on the entire manufacturing operation, from design to production.

Overall, the company's management feels it has met these goals. In the process, management planning itself has become more long range and effective. According to the vice president for manufacturing:

> We're doing more up front planning and simulating. Anybody in heavy manufacturing used to do a great deal of hunting and pecking. Things were done by seat of the pants because you couldn't envisage all the variables. Now we can manage with more finesse. It makes the management job tougher but opens a whole vision up.

As a result of its heavy investment, the company's management has changed its thinking on shop floor priorities. In the 1960's the company sought to keep the worker busy by maximizing the output of direct labor. Machines were grouped around the operator. If a worker were tending two machines in 1960, the same person might be operating five in 1970. In the 1970's the emphasis turned to the productivity of capital. Systems were designed to increase the output of ever more capital intensive equipment. Today, less than 5 percent of manufacturing cost is direct labor, according to the company's definition.

An important element of maximizing machine utilization appears to be minimizing human intervention in the process. Consequently, systems are designed that seek to fully automate the transfer of materials and, wherever possible, the loading and unloading of machines. Where this is not possible, computer systems are deployed to closely track the production operation. These systems seek to give the production supervisor "greater control over the work environment," according to the vice president for manufacturing. At the same time, the activities of the supervisor also come under closer scrutiny.

For workers, the introduction of programmable automation raises important issues concerning skill and autonomy on the job. There is little dispute, for example, that the introduction of numerical control has the potential to lower skill requirements compared to conventional machines. The vice president maintains that "NC complements an unskilled work force." The craft skill that enabled a machinist to work according to well-developed rules-of-thumb is no longer available, he said.

> In the old days an operator would make a scratch on a lead screw for part 839, or take up the screw 3/4 of a turn. Those operators are gone. Now, if you push this button it takes you up to the scratch line.

To achieve the maximum usage from capital intensive equipment, the company maintains that it will require greater flexibility in deploying workers. Moreover, by reducing minimum skill requirements, management feels that workers from one area of the plant will be more interchangeable with workers from another area. The company's desire for greater worker mobility, however, could conflict with traditional labor practices. The union feels that existing work rules provide job security and protection from arbitrary transfer or favoritism.

In the development of many of the systems discussed in this study, the company has played a pioneering role. As a result, there were important constraints that have affected the introduction and deployment of these technologies. The vice president for manufacturing lists some of them:

-- Major difficulties in the materials management area. There was a lack of systems people and resources to develop new manufacturing technology.

-- Managerial resistance to change. Many managers did not see the need for the "flow through" management concept. They questioned the need for innovations such as day-by-day accounting.

-- Lack of off-the-shelf systems technology. In the early 1970's, the biggest obstacle was the lack of developed software and the necessity to design many new approaches internally.

-- Slowness of machine tool vendors. The small and fragmented nature of the machine tool industry caused problems in diffusion and standardization.

-- Reliability problems with controls. The reliability of early solid-state efforts were "marginal if not sub-par. Everytime a truck went by, it would throw your program off," according to the vice president.

VI. PLANT DESCRIPTION

The research team visited two complexes, one manufacturing components and the other a tractor assembly facility, in a city that is an important center of the company's activities. The company has been conducting manufacturing on the site of the manufacturing plant since 1918, when it purchased an existing producer of gasoline engines. The assembly plant was opened in 1981, at which time tractor assembly operations were transferred from the component complex.

The component manufacturing plant is an enormous complex of over 6 million square feet of floor space. It includes 120 buildings and 5,000 machine tools, and employs about 10,000 people at capacity. It is subdivided into staff, foundry, drive train, special products, and hydraulics groups. The research team briefly toured a foundry, a transmission assembly line, a hydraulics manufacturing facility, a flexible manufacturing system, and an automated gear line.

The tractor assembly plant includes 2.1 million square feet of usable area sitting on 1,300 acres north-east of the city. The plant's seven buildings are basically single-story structures and designed for easy capacity expansion. There are three basic production areas: manufacturing systems, wheel manufacturing, and tractor assembly. The diverse parts and assemblies made in the tractor assembly complex, and many from the component works, come together in the 19-acre tractor assembly building. In 1981, the plant was given an important award by an engineering society for its leadership in the development of computer-integrated manufacturing.

VII. AN EXAMINATION OF THREE PROGRAMMABLE SYSTEMS

To explore the effect of programmable automation on the work environment at the company, three major systems were selected for closer examination: management information systems, particularly a labor reporting system; the material handling system in the tractor assembly plant; and the flexible manufacturing system. Each is a major installation of computerized technology. While they are only three of the many programmable systems installed by the company over the last decade, and must be seen in the context of the company's overall strategy and objectives, there is also a benefit to examining each of the three systems separately in an attempt to understand the particular work environment effects of individual installations of programmable automation. In taking a closer look at these three systems, both the differences and commonalities among separate systems emerge with respect to their impact on the work environment.

When examining these three systems and their effects, it is important--although sometimes difficult--to distinguish between those effects on the work environment that are caused by problems present during the implementation of a new and complex system, and those effects that are intrinsic to the system as it is designed to operate. The latter are the long-term effects of the introduction of computerized automation: those changes in the work environment that persist after the original debugging has taken place. Even 2 or more years into the life of a new system, however, implementation problems may remain because of the complexity of the technology; thus the work environment effects of the implementation process may also have an ongoing impact.

Management Information Systems

One of the company's most important automation efforts is a series of interlinked computer systems. Different factories, for example, are linked by the Company Wide Interfactory System (CWIS) so that the components plant has immediate and up-to-date data on production requirements from the tractor plant 7 miles away or from a European plant several thousand miles away. CWIS, in turn, is linked through a master scheduling system to a material requirements plan (MRP) to coordinate inventories and order materials. The MRP is tied into a labor reporting system that is used in most of the buildings in the components complex and in the tractor works. The goal of all these systems is to provide "credible, consistent information throughout the organization." As one manager put it, "Our problem has never been fixing problems, it's been finding problems," and these systems are designed to illuminate the activities of the entire manufacturing operation to make it more manageable.

In this section, the focus is the work environment effects of a computerized labor reporting system, called the Terminal Labor Reporting System, and some additional computerized scheduling systems. Consider first the labor reporting system. In the past, a worker filled in a daily time ticket that reported the projects worked on during the day. The payroll department calculated earnings from this form and production departments updated inventories on a daily basis. With the new system, the process begins with a department scheduler determining open orders and material availability by using the Shop Floor Support Scheduling System, a related computerized network. The scheduler then produces a work schedule and a computerized job order, which goes to an operator. After completing the job, the worker takes the ticket to a shop floor terminal in the work area to report the labor completed. Also, anytime an operator stops work, or goes on or off incentive pay, the worker is supposed to report this through the system. This is done electronically by scanning the work order and keying in the number of parts produced. After this is done, the Shop Floor Support System updates the inventories. Finally, a hard copy of a Daily Time Report is given to the departmental supervisor who checks it and submits it to payroll.

This seemingly simple change from manual to computerized labor reporting carries with it extraordinary organizational implications. While much of the same information was available with manual reporting, the ability to have quick and easy access through the new system gives far greater visibility to all operations. The foreman has a much more immediate idea of what the worker is doing. At the same time, the general foreman has a much greater knowledge of what the foreman is doing, and the same holds true throughout the operating chain of command. The way information is gathered and defined has important power-related implications for individual and departmental autonomy in the organization. Increased visibility can easily translate into increased control.

Effects on Supervision

The labor reporting system has a significant effect on the job of the first line supervisor. The system is designed to "bring more computer power to the supervisor," according to one manager. It is intended to facilitate better planning by giving the foreman a clearer idea of where materials are, what people are doing, and what bottlenecks might develop. If a machine breaks down, the foreman can look at the parts that have to be made and more easily find alternative routings. If alternatives are not available, the foreman can instantly inform the department that is expecting the parts. Also, instead of having to chase parts through the shop, part numbers and locations can now be called up on a screen. One systems manager told of using the system to trace 2,500 parts through the entire manufacturing complex down to the correct storage areas and specific containers.

Scheduling becomes a matter of fact rather than opinion, according to the system's proponents. The manager of the components plant summed up his view of the value of the system by saying:

> We've had good results in the past, but things could get out of control. With this system, they're good and consistently good. The supervisor no longer has any excuse. He knows what his resources or problems are.

The supervisors interviewed had mixed attitudes about computer systems in general, but were quite positive about the labor reporting system. Speaking about computer systems in general, one production foreman expressed the following reservations:

> My primary fact in life is making production each day. Sometimes the computer doesn't get me where I want to go so I have to work around it....Computer engineers are analytical. They like to make rational decisions, but in the short term we have to get the parts out.

One factor unquestionably affecting his viewpoint was the difficulty of the installation.

> At the time they put these systems in we were trying to build 190 tractors a day in two places. It took me time to get confidence in the numbers. It's always easier to deal with something you're familiar with.

This foreman viewed the labor reporting system as a major step toward better control of his department. At a touch he can call up on the computer's video screen an extraordinary level of detailed information about every aspect of his department's activities. Information such as:

-- general payroll data on a worker, including shift start time and lunch time, with any pending changes noted.

-- off-incentive inquiry and update. This tells the supervisor whether any workers have gone off or on incentive, when, and why. John Doe, for example, might have gone off incentive at 2:45 because of improper blueprints.

-- labor inquiry. This provides a detailed analysis of all reported labor for any given worker at the time the inquiry is made. Any previous data for a given employee for the last two weeks can be retrieved on the video screen and earlier data is available on microfilm.

-- daily attendance inquiry. This tells the supervisor the attendance for the entire department. All absent workers are listed and the names of those who are temporarily off the job at the time of inquiry are also displayed.

-- daily time reports. This is a summary of what the worker did for an entire shift and is sent to payroll after the supervisor audits and corrects it. The supervisor must approve all off/on incentive transactions.

One production foreman described his enthusiasm for the system.

> I've been in the business for over 20 years. This is more accurate, retrievable, and trackable than anything else I've seen. It is a major enhancement for looking at attendance, earnings, and absenteeism. Something has to happen every hour of every day with an employee. Everybody in the factory has to be someplace and this is the tool we use to find people. At 7:01 we can see who's in the department without seeing people. Before, guys might be punched in and not there or they might scrap parts and not count them.

A skilled trades foreman echoed the enthusiasm.

> Before, someone's buddy might punch them in. Seldom was anyone late for work. I have 19 people throughout the plant working for me. I can call up on the tube who's in and where they are. I know who's there and we all carry radios....If I need to know how much labor has been put in on a job I can check it. We also know immediately the materials that have been used and if preventive maintenance has been done. The information is available for what's been done in the past....Maintenance parts are a big item to us. The system tells us the location and cost of spare parts and, if I see I don't have something, I can get it rushed in.

With this system, a production foreman gains insight not only into the total number of parts produced on a shift, but how the worker actually spends the time. An important objective of this information is to ensure that workers follow established methods on jobs or, in those cases where the worker has developed a superior system, to see that the jobs are retimed. While the incentive system rewards extra effort, operators have a set of unwritten rules in most departments as to how many extra parts should be produced. In many areas, 130-140 percent appears to be a normal ceiling. If someone were producing consistently at 200 percent it would invite retiming, because it would call attention to the fact that a job could be done in substantially less than the prescribed time. Were this rate sustained for a full day, it would be apparent with conventional labor reporting. But if a worker produces the number of parts corresponding to a full day's work, yet is done with work 2 hours early, this faster rate would not be obvious with the conventional system but would clearly show up with the computerized system. The worker could seek to beat the new system by not reporting completed work until the end of the shift, but this could prove troublesome if the supervisor noticed the discrepancy between the computer information and the actual situation while walking through the department.

The computerized system is also capable of flagging unauthorized worker responses to downtime. An operator is supposed to record downtime on the timecard because it is paid at a different rate than incentive work. In the past, a worker might keep the timecard in a locker, and record any downtime in pencil. After the machine was fixed the worker might pick up the lost production for the time the machine was down, thereby increasing both total earnings and total production for the day, even if it required running at 200 percent of production for the time involved. When the final timecard was turned in, the downtime would not be on it.

A further target is "banking", where a worker will secretly stockpile parts on a good day to use on a bad day, thereby evening out incentive earnings. Since the foreman now has a clearer idea of the number of parts entering and leaving a department, the diversion becomes obvious. According to one foreman, "Everybody has a bank. A timecard is easily manipulated. But with the computer system, there is no getting the eraser out. Everybody knows that the machine has no conscience." When asked if the computer system meant he no longer had to worry about banking, the foreman replied: "I didn't say that. It's easier to control banks with the computer, but you still have to worry."

The company prohibits banking as part of its attempt to reduce inventories and gain greater control over the flow of parts through the plant. One worker interviewed said that his only incentive to keep a bank was the erratic scheduling in the shop, which he attributed to the computerized scheduling system. If parts were consistently available, he said, banking would not cross his mind. A manager at the components complex said, "Operators see fewer piles of material sitting around as less material available for them to run. We see it as better control." In this process, the foreman loses a considerable amount of autonomy concerning the discipline of workers. Once a worker goes off incentive, the foreman no longer has the opportunity to wink at an after-the-fact correction.

Workers' Reactions to MIS

Workers interviewed had differing attitudes about the labor reporting system, depending on the nature of their job. Workers on assembly lines tended to view it in a generally benign way. Many expressed favorable sentiments about less paperwork and less difficulty punching in and out. Workers who controlled the pace of their jobs on stand-alone machines had a different view. They complained about serious scheduling problems in the factory and increased managerial control over their activities.

Scheduling Problems: The complaints about confused planning contradict management's strong assertions that planning has dramatically improved. There are several possible explanations for this. One explanation is that scheduling has in fact deteriorated, but that the data on the computer give management a false sense of security. As one worker put it, "They have all the information, just not the facts." A second explanation is that planning has improved, but that workers are unaware of the overall scheduling method and therefore are unable to properly evaluate what is taking place. As one manager familiar with the hydraulics plant stated, "Ten years ago, we had much more inventory sitting around. Today we have much, much less, and the uptime of our (intermediate) assembly lines is better than ever. Operators don't see that."

The company maintains that while there are occasional scheduling problems because of machine downtime or problems with vendors, there are no significant problems with the computerized scheduling system. While workers' observations suggest a widespread pattern of stop-and-go production, management believes that this happens only in isolated instances. To some extent, the company asserts, what operators see as erratic scheduling is also the result of business decisions and the new flexibility that the computerized scheduling system permits: because production can be planned on a day-by-day basis, the company can now make the decision to rush jobs through production. One manager said, "We may decide to work overtime to satisfy a rush order, knowing that it means we'll be out of work on Monday. We try to explain this to our operators, but we're not always successful."

It is unclear to what extent the scheduling that workers complain about is the result of problems in the scheduling system itself, of problems in the production process such as a faulty machine, or of deliberate business decisions on management's part.

Scheduling may be better overall, as management asserts, or worse, as workers claim, or possibly some of each. In terms of the work environment, however, workers feel there has been a significant deterioration in their ability to produce at a steady pace. This affects both the amount of overtime workers must put in and the amount that they get paid, since an operator cannot be paid at an incentive rate when there is no work available. All the workers from the hydraulics building who were interviewed believed that erratic scheduling was the result of the scheduling system or of the way it was being used.

One worker in the hydraulics building describes his perceptions of the scheduling.

> The right hand doesn't know what the left hand is doing. They depend on that computer for all their information and it seems like nobody really knows what the computer is all about; yet I don't know if it's just the people programming it or it's upper management that's feeding it and the supervisors on the floor aren't sure what it's telling them to do that's got production going whacko at times. But it just seems like nobody's in line. Management isn't in line. They're not following any kind of pattern as far as scheduling....It just seems like it's going around in a circle that nobody really knows what to do.

The same worker further complained:

> If you go up and ask the supervisor why you have to do this or why you have to do that, he doesn't really know. The tube told him to do it so that's what you do. And the scheduler is the same way. The scheduler usually schedules the work and he's not sure why you have to do it, but that computer told him to do it so that's what he's telling you to do, and nobody really knows why. It seems kind of a farce....They just kind of lost the common sense element of running that place....they're wanting this guy over here to work overtime and he has no work available whatsoever and they're scheduling for 12 hours a day and he says, well, why should I work 12 hours a day when I have nothing to do?

A worker in another department claimed "It seems kind of crazy. The computer says they have 3,000 parts and they can only find 100." He elaborated:

> The other day they brought out a sheet saying we had 100 hours sitting out there to run. I added it up in my head. We're set up so we had 20 hours sitting there. So where are the other 80? I don't see it anywhere. And then he's pointing at a sheet, and I said well those are done, we shipped those yesterday.

A worker in a third department pointed to scheduling problems with the computer system and contrasted these with the way things were done manually. In his view, a central failure of the new system was the inability to conveniently correct things when a problem arose.

> The general brainstorm was to keep a daily inventory to keep an even flow of work coming through. But in actuality what it does is, in Department A they've got my parts and I'm out of work but until there's a move order hung on it from the computer. I can't get it. I don't care if I can see it. I don't get it. And so we've got a bunch of layoffs and we've got backup people working overtime. Well, that's scheduling. And that's the computer that did the scheduling. You'll be out of work Monday and Tuesday, and work 12 hours Wednesday, Thursday, Friday and Saturday, and be out again Monday. And that's the way it's running daily in there, instead of that even flow. And the supervisor had the even flow. If I needed that part, he'd walk down, or he'd call the supervisor down the other department and say, "Get a move order hung on that." The clerk would make the move order out, put it on, and the trucker went and got it, and I went to work. But with the computer you don't do it that smoothly.

One worker pointed to the integrity of the data going into the system, and management's reliance on the data, as the problem.

> Common sense has nothing to do with it anymore. They watch the tube so closely that they've taken every human aspect out of it. It's machine oriented. The whole thing is just run by one stupid machine with information being fed into it that is not necessarily all as current as it should be or correct as it should be, I guess. I'm not sure what it is, if it's current or correct.

One worker who had complained about the system did not view computers as the culprit, but the particular way this system was set up and run.

> I'm sure computer automation will eventually have all this stuff. A good program, a good system on scheduling could take care of total scheduling. But the problem is they have intermediaries right now....eventually the salaried person is going to be non-existent. Really, they're more in danger than we are.

Some workers complained about excessive overhead on the system.

> We used to have one foreman in a big department, and maybe a scheduler, or if it was a big enough department, most of the foremen did their own scheduling. Now we got at least a foreman, maybe two in the department, who have to know how to schedule and all that. Then you have an expediter....

Increased Rigidity: Some operators felt that with the labor reporting system their input was viewed as superfluous, any personal relation with the foreman is severed, and rules are more bureaucratically enforced.

> They've kind of turned the operator into a robot. He's the last one to be contacted about anything, and he's probably more knowledgeable about where the parts are that he has run and where they're going than anybody else in the factory. They'll run to a stupid tube, they'll run to the next department, they'll run to the management higher up. We just stand there and do our little job all day and that's about it...We've kind of lost communications between the workers and the management. It used to be when you were in a department, you'd go out and shoot the bull with the foreman and find out what you're going to run tomorrow or the next day or what's coming up, and they don't know anymore. They have to look at the tube to find out what's going on and that changes from day to day.

Workers felt that in the past they had played a role in expediting the work of their department, when they had been able to go find the next batch of parts and move them to their machines; the new system, and the organizational rigidity that accompanied it, had interfered with their ability to exercise initiative. From the company's point of view, workers have no role in scheduling; therefore, if the computerized scheduling system interferes with the ability of the worker to intervene in scheduling, no problem is created. This may, in fact, be a desirable outcome. According to one manager, operators often have their own agenda when it comes to scheduling.

> In the past an operator might have said, "I'm out of work. Why don't I run part A now." Because he likes part A, because it makes him good money. But what he doesn't see is that down the road, we need part B before we need part A.

A worker who runs a radial drill commented unfavorably on the lack of flexibility that foremen now have, and the inefficiency caused by this new inflexibility. He gave the example of authorizing bonus days. These are contractually-provided floating holidays for which the worker is supposed to apply one week in advance. In the past, if a worker's machine went down for a major repair at the end of the shift he might request the following day off. If he came in, he might have to stand around waiting for his machine to be fixed, thereby lowering incentive earnings. The foremen would usually agree to these requests because they saved the company money, since the worker would sooner or later take the day. The foreman would then backdate the request for the bonus day. With the computer system, however, requesting the following day as a bonus day would trigger an error. The worker commented:

> The computer is programmed to do it by the book. It takes all the leeway the foreman used to have. The foreman could do a lot of things. Not according to the contract, but according to good ethics. He could be a person, he could be an ordinary person, where now you go up to him and say "Can I come in an hour early tomorrow, I got to get off an hour earlier, I have a dentist appointment?" You can't do that. It's in the computer. Your starting time is 7:00, you know, which is totally ridiculous.

Even with the new system, the supervisor has some leeway. By allowing a worker to punch in completed work late in the day, adjustments can be made in a way reminiscent of the time card. But the supervisor himself is then open to an audit which could prove embarrassing or worse.

Monitoring: The monitoring aspects of the labor reporting system create fears about a computerized "Big Brother" among some workers.

> It's 1:00 and I'm not done until 3:30, so I go over and I punch my work in that I've got 24 pieces done, and they happen to go in there and the computer tells them that "Hey, this operator punched in his work at 1:00, how can he punch in his work before he's done?" In other words, that computer is saying, "hey, this guy got done at 1:00." That scares the hell out of me. So I wait till it's time to go home. You know, it's a scary feeling to have a machine know what it knows. And I don't know what it's telling my foreman or my boss or whatnot. It's just like a watchdog over everybody. I don't like that. It's scary knowing that somebody knows more than they probably should know. And in that way it intimidates people, too, because there's people in there with a lot of seniority that have been there a lot of years. I feel sorry for them because they are so scared. And to start 25 years ago and to where now this computerized age has come upon us quicker than hell as far as I'm concerned. I know it's been there, but it's hit me fast, and I can just imagine what they're going through. It's got to be hell, because even learning how to punch in and punch out on the thing was a major accomplishment for them. And they still don't understand it, and they never will understand it enough to even be able to talk to somebody about it.

Another worker described the initial reaction to the system.

> I think people didn't understand it. They felt threatened and I suppose there still is a certain amount of skepticism, the feeling of Big Brother is watching your every move, because with more and more development, that's exactly what they can do is watch over you. Now I think they've gotten used to it. But if it ever progresses, the capabilities progress, to take that same computer and have your machine piped into the office to where they can literally sit without even leaving the office and punch up and see if you're running. Once that machine stops then the computer is going to show it stopping. Where's the end? If you're gone more than 5 minutes, they're going to come out and look for you.

Whether or not the company actually uses this information for disciplinary purposes, workers' apprehensions about the possible use of the information remain.

Scheduling in the Toolroom

In the toolroom, an independent scheduling system supplements the labor reporting system. Toolmakers are highly skilled machinists who build fixtures and other work-holding devices for production. On complex assemblies, they may have some of the individual parts made by toolroom machine operators. These operators usually specialize in running one toolroom machine such as a lathe or a mill. Previously, a toolmaker would directly discuss with the machinist how the part should be made. With the new system, however, the toolmaker brings the request to a scheduler who then assigns the job to a machine based on the job's priority and machine availability. This procedure gives management a much clearer idea of the workload in the shop and the apparent ability to schedule the machines more efficiently. But toolmakers interviewed complained that it seriously disrupted their ability to process jobs. They claimed that the vital personal contact between the toolmaker and the machinist was severed. A toolmaker described the process:

> Where you used to have a toolmaker, at least if he wasn't going to work himself he could take it to a machine hand and stand there and explain to him what he wanted and how he wanted it done, what he wanted left for stock or anything. Now you take it to somebody that's never run a machine in their life. You tell 'em it has to go to a certain machine, it's got a due date on it so they put it in line with any other jobs that may go to that particular machine and you don't know when it hits that machine. It may be on a different shift and the guy doesn't know you that runs that machine and you don't know him and boy, you've dealt with lots of screwups. I mean, there's no communication except between you and the person that runs the CRT that hasn't run a machine.

According to this toolmaker,

> It takes away your ability to make decisions, or to follow through on a job if you can. They'll take it over there, and when it comes back it comes back. What's frustrating is the fact that the foreman comes up and says "where's this job at?" And you look at him and you say, "well you're supposed to be able to go over there and look at the tube and it tells you where the job is at. I don't know, I took it over there 3 weeks ago and I haven't seen it since." And so he goes over there and they look on the shelf or something and say, "oh, here it is." Well, that's 3 days overdue. There's no sympathy.

In the minds of the toolmakers interviewed, the system dramatically increased the number of salaried people so that they referred to it as the "job security system" for salaried employees. Furthermore, the toolmakers regarded the system as actively obstructing their work, at least in its present form, whatever its advantages might be to management in terms of increased ability to oversee shop operations.

The Tractor Assembly Plant: Computerized Material Handling

At the tractor assembly plant, parts manufactured elsewhere are brought together for assembly into a finished product. The chief technical problem in the plant, therefore, is to ensure that the proper components come together at the right time. At the core of the plant's operations, nine minicomputers operate ten systems that move materials through the plant and control various operations. Although the application of computers to process control is extensive, the unique feature of the operation is that these production computers also perform data processing and business management functions. According to the plant controller and head of data processing:

> The host computer is running our business just as it does in traditional manufacturing environments. The difference is that it is telling minicomputers instead of people what output is expected from them each day.

The minis are also capable of communicating with each other. They are programmed to ensure that assembly does not begin on a tractor unless all the major parts are ready. The minis transmit messages concerning part availability and, when necessary, order delivery of the part.

The materials management function has undergone the most dramatic transformation. There are seven computer-controlled high-rise storage systems in the factory. Most parts arrive first at the largest of these systems in the receiving building. The system is over 80 feet tall, has 16,000 storage compartments, and is served by 6 computerized cranes. The other systems, although smaller, perform similar functions for work in process.

When parts are needed in assembly, the computer guides a crane to the appropriate storage area; the parts are retrieved, and then pass by an electric eye that makes the appropriate adjustments for inventory purposes. The company maintains that over one-half of the work force in this receiving area has been eliminated as a result of this system. After removal from storage, the parts are transported by overhead conveyors that travel to and through the buildings in the complex. This cuts down on the manual movement of parts with fork-lift trucks. Management reports that these automated storage facilities have been pivotal tools in reducing inventory and maintaining more uniform "flow".

Separate minicomputers control conveyors in the tractor assembly area and in a paint area for subassemblies, and regulate the movement of finished tractors through the final adjustment and repair area. The computer control in the tractor assembly area is particularly complex. Eight models on three separate assembly lines are fed into a surge area where they move through a single paint line and then out into three assembly lines.

Four cranes must unload the three chassis assembly lines and load the final lines in correct sequence. In the paint booth three robots are employed, including one that sprays the tractor from a pit in the floor, a particularly taxing job for a human to do. These robots are joined by two human painters who do the finish work.

The setup of the plant provided some tough technical challenges. The plant engineering staff felt that an appropriate rule of thumb on the installation of advanced systems was "agony for a year." In some cases, even this underestimated the difficulties involved. When asked what would be done differently today, the plant's manager of manufacturing engineering replied:

> We would bring in the electrical and mechanical skilled trades people earlier so they could see the equipment installed. The learning curve for skilled trades is a long one. We would have our own skilled trades people look over the shoulder of the installers.
>
> We also underestimated the number of electrical engineers we needed. We had to double or triple them in a year.
>
> We would also have brought in more systems people earlier, especially systems people with shop savvy.

Overall, plant management feels the systems are indispensable to a more orderly "flow", a repeated company theme. The controller maintains, "The management of what is going on in the shop has changed. The shop no longer can do what it wants but must do what they're told, since everything is so integrated.

Changes in the Work Environment

On one level, the work tasks in many areas of the plant, particularly on the assembly line, are not directly altered by computerization. An assembler, for example, still bolts a part onto an engine in the same way as before. On another level, however, the organization of the plant, especially the delivery of parts, is considerably revamped. In this area, the workers interviewed had a substantially different perception of the plant's operation than management. Rather than smooth flow and little downtime, some workers spoke of persistent downtime and an inability to correct the situation easily when a problem did occur. The highly integrated nature of the system caused one electrician to refer to a "domino" effect. A relatively small problem at one point of the operation could quickly be transmitted to other areas. Downtime is not unusual in a system of this complexity, nor does a certain amount of downtime mean that the system is not meeting its production goals. In terms of this study, the important consideration is the workers' perceptions of erratic operation rather than the actual downtime. While the research team was not able to ascertain the amount of downtime, it is the perception and its consequences that constitute a work environment effect.

One assembler, who is a union steward, addressed the issue of downtime:

> The difference between the new plant and the old plant downtown is the amount of downtime. Our quota is 48 tractors a shift, but the line is run at a speed that would turn out 53. Those extra five slots are put in because of all the delays we experience...In the two years that assembly line has been in operation we haven't had a perfect day except for one day, and that was last Thursday, and our supervisor bought us donuts on Friday...Some days like yesterday we only got 36 tractors when we were supposed to have 53.

The downtime appears to be caused by failures in the high-rise storage system, the interplant delivery system, or malfunctions of other computer-controlled equipment rather than problems with the computers themselves. The surge area where the three chassis lines converge into one paint line is particularly troublesome and capable of slowing down the entire plant. As one worker put it:

> Those big cranes out there for some reason get the wrong instructions from the computer. They'll crash into each other, or maybe they'll let the front end of the chassis down and not the back end down. I've seen them fall off that big crane.

As a result an electrician and mechanic are stationed by the surge area to service it. There is also an electrician and mechanic on each of the seven high-rise storage areas. This type of maintenance staffing is standard manufacturing practice, but runs counter to the popular perception of automation requiring no human intervention.

Downtime in a critical area can be difficult to correct manually, according to the workers interviewed, leaving few if any alternative ways to continue production. One assembler maintained that "downtown if you have a problem you just jump in a forklift and get the part; now you have to wait."

These malfunctions are particularly aggravating to the workers because they tend to be frequent and of short duration, which interrupts their incentive pay. A stoppage must occur for longer than 6 minutes for a worker to receive a more favorable incentive compensation and many of the interruptions tend to be in the 2- to 3-minute range. As one assembler put it, "Under the old system the line rarely went down. When the computer system goes down it affects my paycheck, which affects me."

The downtime issue is exacerbated because it is electronically monitored. Under the old system,

> If the foreman wasn't around to catch the clock, you could write down 20 minutes when you were only down 15, pick up a little bit of extra...This system has a tape in the office that records when that line goes down, and records when it starts back up...It gives the company an opportunity to monitor us a lot closer on that particular situation.

There was some dispute between the workers interviewed over how endemic these reliability problems were. Some workers felt that the situation could get worse when higher production is run, particularly on two shifts. One worker "looks forward to it getting better." He maintained, "We said it would never work right. It's amazing how well it does work." Whatever future developments may bring, however, the 2-year debugging process shows the complexity of operating computerized systems on this scale.

Automation and Changes in Work Methods

Two areas where production methods have been considerably altered are in painting and welding. Most workers interviewed were glad to see the elimination of the painting job, provided it did not result in unemployment. One steward stated, "I think some of the new technology is probably good, like the robot for painting tractors. That was one of the dirtiest jobs here. Being in the pit painting, you had to paint all day long."

On the welding machine for the tractor cabs, jobs that were formerly done by independent pairs of welders are now done by 20-person crews. One welder stated that the task didn't change, but "we're now all in trouble when the machine goes down. We're tied together much more tightly."

Automation and the Effect on Maintenance Workers

The tasks of skilled maintenance workers, particularly electricians, have also been changed significantly. One electrician stated, "This new technology is scary as hell but I love it. My background as an electrician was in house wiring and now I have to troubleshoot these systems." Most electricians interviewed felt the diagnostics now required more skill than previously, but often the repairs were easier, particularly when only a circuit board was changed. As one electrician put it, "It's more skill and less hands on." One electrician complained of the trade being fractured. He said the company's policy was for "Bill to pull the board out, Frank to repair it, and Joe to send it to the factory."

A new aspect of the trade concerns remote diagnostics. An electrician sitting in a control room, for example, uses a CRT to troubleshoot a fault on the interfactory delivery system that might be in another building. This requires close coordination and cooperation with the operator or other individual on site. The electricians also spoke of the need for increased cooperation with other trades. Whereas before, a mechanic or an electrician might have worked alone, the complexity of the new machinery often made it more important to have the two trades work closely together, especially for the purposes of diagnosis.

Skilled trades workers in the tractor assembly factory said that stress and pressure could be a serious problem on their jobs. The integrated nature of the operation made the failure of any machine linked to the larger system a more serious problem than the failure of a stand-alone machine. The "domino effect" causes many workers, not just those working on an individual machine, to be idled by a breakdown. An electrician described how the high level of integration of the system creates pressure for maintenance workers like him:

> When one part of the system stops, it all comes to a screeching halt. If the line goes down, all the people on the line stop working. All the conveyors bringing parts into the line have to stop, and all the people feeding those conveyors have to stop. Whoever the individual is who does maintenance in that area has to get it all going.
>
> You know that if you don't get going pretty quick, there'll be a few white collar people around you pretty soon. If the maintenance man can't figure it out, he gets excited and a little bit agitated.

All the electricians interviewed complained of inadequate training. The rate of technological change makes this a crucial problem. As one electrician put it, "Yesterday's technical journal is today's birdcage paper." The sense of being inadequately trained adds to the stress that some maintenance workers reported feeling. Furthermore, supervisors were of little use in helping maintenance workers to learn their jobs more completely, according to the maintenance workers interviewed. One electrician felt that skilled trades supervisors were becoming increasingly superfluous because they had no direct technical experience with many of the new systems. "Supervisors don't know what is going on. They're afraid of changing technology because you might ask a question and they won't be able to answer." Altogether, maintenance workers felt that they had had insufficient preparation for their present jobs--a fact implicitly acknowledged by the manager of manufacturing engineering, quoted above, who said that in retrospect the company should have brought skilled trades workers in earlier in the installation process.

The Flexible Manufacturing System

One of the most sophisticated installations in the manufacturing complex is a flexible manufacturing system (FMS). This system combines numerically controlled machining centers, automatic part transfer, and overall computer control into a highly integrated production network. In this section the focus will be on the motivations for selecting this system, the process of installation and, finally, the effects on the work environment.

The company did not start out with the intention of purchasing an FMS. The manager of manufacturing engineering at the components plant recalled, "We had a problem looking for a solution. We didn't know what an FMS was." The problem was how to manufacture the transmission case and clutch housings on a new generation of tractor. Moreover, the company was planning yet another generation of components that would make the first set obsolete 5 years or so after the initial introduction.

Three alternatives were considered.

-- Modify the existing transfer lines. While this was the cheapest alternative in terms of direct cost, it meant shutting down the lines for 6 months. Production schedules and inventory costs made this prohibitive.

-- Stand-alone NC. The manufacturing cost would have been too high using this alternative, although the flexibility would allow the machines to be retained for the second generation of parts.

-- New transfer lines. This would have had the advantage of low manufacturing cost, but would have required a high investment and would not be adaptable for new components.

The company then took a description of its manufacturing problem to eight different vendors. Out of these discussions, the FMS emerged as the desirable alternative. According to the manager of manufacturing engineering, "Our thinking was to use this equipment for 5 years and then introduce a transfer line for the next generation of transmissions. We could then adapt the FMS for something else."

As things turned out, the flexibility of the FMS contributed two additional advantages, one for design and the other for marketing. The system gave product engineering a badly needed additional 9 months to finalize the part design since the flexibility of the system meant that modifications to the product could be far more easily incorporated. Also, marketing's projections for sales volume changed four times during the planning stage for purchasing the equipment. At one early point it was felt that fewer than half the final number of machines in the system would be sufficient.

The final design of the FMS included nine CNC machining centers, three head-changer type machining centers, computer-controlled chain driven carts, and overall computer control. Nine different part types in varying quantities can be routed through the system simultaneously. The computer automatically shuttles the part to the appropriate machine that has the shortest queue. If one or more of the machining centers are down, the part can be rerouted to a different machine. Thirteen different fixtures are carried on the carts to handle the different setups on the various components. Once a part is loaded, it is theoretically untouched by human hands until it leaves the system.

The implementation of a system of this complexity is an exceedingly difficult task. The system was actually ordered in March 1978 and the company took delivery of the first five machines in August 1980. These machines and the material handling system were in operation by January 1981, at which time major construction was completed. All 12 machines were installed and under computer control by May 1981.

The start-up was further complicated by a strike at the machine tool builder just prior to the beginning of the installation. The semi-finished machines were shipped without full factory testing and installed by non-striking factory managers. The company, in purchasing the system, anticipated that software would be the major problem and assumed there would be little difficulty with the machine tools and transfer system. Instead, just the opposite turned out to be the case. These problems carried one hidden benefit. Skilled-trades employees were able to get an early and thorough briefing on the equipment, which the experience at the company's tractor assembly plant suggests might not otherwise have been the case.

On the day shift the system is staffed by three loaders, four machine operators, one tool crib attendant, two machine repair, one electrician, one supervisor, one system supervisor, and one quality supervisor. There are fewer people assigned to the system on the other two shifts. At the load station, a video display screen tells a loader which part to clamp into a fixture. One loader feeds each major loop in the system and a third loader operates a part washer. Within the system itself, each operator is assigned to three machines. The operator is responsible for changing tools when instructed, inspecting parts, responding to any unusual problems, and cleaning the machines. For most routine tasks, the system determines the timing. When a tool has been used for 75 percent of its expected life, for example, the tool crib is signaled so that a new tool will be at the machine when 90 percent of expected tool life is reached. After that the machine automatically stops and a red light flashes. The machine is also programmed to stop after every tenth part for an inspection of critical dimensions, turning on a light and setting off a siren. Moreover, the operator has a cathode ray tube on each machine which can help diagnose faults and prompt certain preventive maintenance activities.

The system is designed to minimize downtime. If a machine or two are down, parts are automatically rerouted to other units. If the transport system goes down, however, the consequences are more severe. Moreover, small problems have a tendency to grow quickly. When the line is stopped, for example, the carts tend to drift from preset positions so that the computer loses track of their precise location. This necessitates a more elaborate startup.

A key organizational advantage to the company is the tighter control over production made possible by the substantial reduction in operator input on the FMS, compared to stand-alone NC machines. The project manager on the system maintained, "You don't have people you're relying on. Once the computer gets the part, it doesn't wait for a guy who is drinking a cup of coffee." The manager of mechanical services at the plant concurred, "People become the exception here instead of the rule." The manager of manufacturing engineering added:

> The automatic loading and unloading of the system is a significant advantage. The quality level is no longer dependent on the skill of an individual operator. Now a certain minimum quality level is built in.

While the system is designed to operate with minimal human intervention, a visit to the FMS and interviews with operators and managers suggests that considerable operator input remains necessary. Intervention was even more frequent in the early days of the system, partly because of recurring problems such as a problem with the transport carts that required their redesign. The system itself was set up in a way that allowed for substantial operator input. The project manager for the FMS states:

> We had to untrain people from intervening. It took time for people to gain faith in the system. We used to have optional stops giving the operator the ability to stop the machine. We had to take this out of the program. We'd walk by and ask "Why is the machine stopped?" The operator would say, "I want to check the piece." We would then ask, "Should you check the piece?" We told them all we wanted was one-in-three inspection.

Today, because of the extraordinary complexity of the entire system, operator input remains critical. The project manager admits that a considerable amount of "tender loving care is necessary," above and beyond routine duties. A tow pin on the cart might stick or an operator might spot a broken tool in a part. At times there are also tool adjustments the operator must make to meet critical tolerances. A number of supervisors commented that the operators are very quality conscious and that the system would not work effectively without them. An operator can see a defect in a part, according to one supervisor, and know where the machine went bad. He further maintained that "a good operator develops a feel for the machine. Just by listening he can tell if a drill is going bad or a bearing is going out."

When the system is operating, throughput--the time the part spends in the system--is exceptionally fast compared to stand-alone NC machines. Because of the complexity of the system, however, downtime is a serious concern. The system was purchased with an expectation of 33 percent downtime, so that anything better than this would be considered desirable. Management provided various figures on downtime that ranged from 4 percent to 20 percent, but some workers spoke of downtime as being even higher. While the research team was there, a malfunction of a machine air conditioner caused the machine to go down, and then further problems delayed startup for about 45 minutes. On the following night several hours of additional downtime were reported. Weekend work had been scheduled to make up for lost production, but a software failure caused this to be cancelled as well.

It is possible that a high proportion of whatever downtime exists will be eliminated with further debugging. It is also possible that better software and improved technologies will remedy some of these problems. But a critical question remains: Is the system designed in a way that allows humans to correct for machine failure, when it does occur, in an optimal way or does the desire for fully automatic operation constitute a roadblock to effective operation?

The one area of the FMS where human intervention is routinely required, as part of the design of the system, is the loaders' job, which has the lowest labor grade of the principal jobs on the FMS. Loaders standing at the periphery of the system load parts onto fixtures mounted on carts. At the end of each shift a load/unload activity sheet is printed. It shows the time that a part comes into the unload area and the time when it is actually unloaded. A running tabulation is kept of the difference between the time it should take to unload each part and the actual time spent, totaling the accumulated excess time. If a number of carts come into the unload area at one time, excess time piles up even if each individual cart is unloaded quickly. One night when an inexperienced worker was being broken in by an experienced loader, over 500 minutes of excess time were accumulated. In this case, the problem may simply have been in the software and therefore possible to eliminate with a more sophisticated program.

The technical complexity and downtime problems associated with FMS have been explored by Donald Gerwin of the University of Wisconsin-Milwaukee School of Business Administration, and Melvin Blumberg of the Fairleigh Dickinson University School of Business Administration. Blumberg and Gerwin maintain:

> The complexity of the new technology is staggering (even to one of the authors who is a graduate engineer). Yet, electricians are being told that since computers are electrical, they should be able to repair them after several weeks' schooling at the vendor's facility. Mechanics who have never had to deal with anything more complex than a gear box are suddenly expected to diagnose and repair a state-of-the-art, electro-hydraulic and mechanical device costing on the order of 8-10 million dollars and not completely understood by its designers.(3)

The results, according to Blumberg and Gerwin, can be high downtime.

> Breakdowns of computers, materials handling systems, and machine tools are a major contributor to lower machine utilization than anticipated, and in some cases lower utilization than less complex equipment. One firm, for example, gets about 15 to 20 percent less uptime from its CIM than from its stand-alone equipment thus reducing management's control over production schedules and compliance with customer deadlines.(4)

The FMS and the Work Environment

The perceptions of operators and loaders about working on the FMS depend in part on their previous work experience and initial reasons for choosing to be on the system. Many operators were previously conventional machine operators and NC operators, with some workers having no machining experience at all. The workers on the system bid for the job, based on their seniority and management's evaluation of their qualifications. Their reasons for wanting the job varied, but there were two recurrent themes: the challenge a new technology might offer and a desire to be part of the "future."

One operator stated, "I find new things challenging, and with something like this it's good to get in on the ground floor." Another operator stated: "If you don't get into it, you won't be able to get by. If you're looking at 15 years or so before retirement, you'll be sweeping floors."

The complexity and expense of the system caused some apprehension among operators. As one operator put it, "When you're first down there you're just nervous. Because everything's so expensive you don't want to break anything. You tear up a boring head and that's $80,000, not counting the production you lose."

Some aspects of the FMS impressed the operators very favorably. The cleanliness of the system, for example, was highly regarded particularly by those workers familiar with cast iron machining. This stems from a sophisticated coolant system that minimizes the characteristic soot of machining cast iron. The operators also commented favorably on the lack of physical labor, although this obviously would not be the case for loaders. As one operator put it, "There is little physical work here compared to a tape machine (NC machine) that you have to load yourself."

The operators complained about boredom, pressure, and oversupervision. Some of these complaints stem from system design, others from managerial policies and practices, and in some cases no clear line exists between the two. Stress was a critical problem for some operators. The considerable capital investment combined with the high visibility no doubt contribute to the pressure. One operator said:

> The pace they try to set is the biggest problem. They're trying to move the thing...they tend to keep pushing people and they aren't giving them the time they need when they're learning and actually when they're running the system because, when you're responsible for three or four machines out of that system, if two of them go down at the same time, you can only be on one of them. You can't be on both....They still hurry people, and they don't expect you to make mistakes, and yet they increase the chances of making mistakes by hurrying you and I've had that happen to me. I was working on one machine when the other one's down and they want to get that one going and there isn't too much wrong with that first one, so I jump over there quick and set this tool quick and go back and then I goofed up. I set it wrong or something, and that's what happens when you hurry your guys.

This kind of pressure on a highly integrated system can have a wider effect.

> On a line like this a small mistake can quickly become a big mistake. They tend to think you shouldn't make mistakes so that supervisor comes down hard. After you make a mistake you're scared so it gets so you can't do your work.

The pressure when things are not going well is combined with boredom when they are. One operator maintained that the job used to be a challenge, but "now its almost boring because its predictable, because you know exactly what you have to do." Another operator was more favorably impressed. Although he also found the job boring, he compared it to his other alternatives, particularly in a weak economy.

> I'm glad I have the job. I've had a lot of worse jobs. I'm pretty comfortable with it, right now. But it does get boring, you know, from time to time but I think you get that with just about everything you do in a factory like that. When you go in and do the same thing day after day after day, you're going to have a certain degree of boredom, especially on this type of job though you do have a few more different situations happening so it kind of breaks up the boredom probably more than other jobs.

When the system is running well, some operators feel that supervision associates "busyness" with productivity. This makes their work environment more unpleasant and interferes with their ability to do the job properly.

> On a system like this there's going to be a time that you're not doing anything. Or at least it looks like you're not doing anything, but you're watching the machinery and you're waiting and you're keeping track of different things. You still have the responsibility so you're actually doing something, but not physically. They want to keep that same aspect where a guy should be busy all the time, and they come out with this cleaning and they find these little nitpicky things to do just to keep us busy.

Management pointed to low turnover as an indicator of job satisfaction for the operators, stating that the first five people trained were still on the system. Some workers commented, however, that there were few good opportunities to bid on other jobs in this economic climate. Moreover, the operators classification was narrowly defined so they couldn't transfer to another job in a different part of the company without also changing classifications.

The loaders interviewed expressed a higher degree of job dissatisfaction than the operators. Their job has also had higher turnover. This is partially due to the fact that it is easier for other workers to "bump" into the loader job during a layoff elsewhere in the plant. The loaders complained about stress and supervision. One loader stated: "The foremen tend to be baby-sitters rather than supervisors. They would like to stand next to you all day long."

During the research team's visit to the plant, a dispute was going on over incentive pay. The operators were being paid on an hourly basis because a formula had not been agreed on for incentive pay to be applied. The loaders were paid on incentive but were dissatisfied by the method with which it was calculated. They claimed they were the only incentive employees at the company whose incentive earnings could be docked under certain circumstances. One loader said, however, that the disagreement involved an individual in industrial relations and that the foremen were open to their ideas on this point.

The electricians, in interviews, said they felt challenged by "high tech", as they called it, but admitted to a generalized apprehension among many of their coworkers about new systems. One electrician explained the fear as follows:

> There's a lot of fear of new technology because it's unknown. When you have the responsibility to fix something, you don't want to be looked at as not smart. One guy might take two days to troubleshoot a machine and another might figure it out in two minutes. The fear of messing something up works on a person.

The same electrician stated that while it "takes a lot to get into the technology, once you're in it things are a lot easier." Another electrician elaborated on the difficulty of diagnosing a system as complex as the FMS.

> These machines are all computer controlled. It's a lot more complicated than fixing a radial drill. Ten different things can cause the same symptoms. The breakdowns are more software oriented, they're diagnostic problems.

A number of skilled workers commented on the need for increased cooperation between electricians, machine repairmen, and operators. One skilled maintenance worker commented:

> You can save a lot of time by people working together and getting along. Otherwise a two-minute problem becomes a two-hour problem. A few years ago you could do it by yourself but now you need two heads, one mechanical and one electrical, and a good operator. The operator knows his machine better than any mechanic or electrician. He knows what any little noise means and how it's different.

A theme repeated by a number of maintenance workers, as they had at the tractor assembly plant, was lack of adequate training. Excessive pressure and oversupervision were also frequently commented on by maintenance workers on this expensive and highly visible system. One worker said,

> Some of the supervisors are always pushing and pushing. With that kind of equipment you don't push. Seeing so many salary people is bad for morale. We're there and we know our responsibility.

Donald Gerwin and Melvin Blumberg did a study in May 1980 of an earlier FMS, installed in 1970 by a competitor of this company. The study included extensive interviews with 18 of the the 20 people working on the system. The sample included 2 foremen, 6 operators, 6 loaders, 2 machine repairmen, and 2 tool setters. The questionnaire consisted of 177 questions, some of which were open-ended. The conclusions were very similar to this study's findings.

> My colleague Mel Blumberg and I found that most blue-collar participants in the American company's FMS--especially those who were loaders and operators--felt that their jobs were stressful and offered little motivation. In particular, they regretted the lack in their work of both autonomy (the opportunity to exercise discretion) and task identity (the chance to complete an identifiable piece of work). At the same time, they had a great need for personal growth and development that was not met at work. Not surprisingly, then, most workers (with the exception of foremen and repairmen) were dissatisfied with several important aspects of their jobs: comfort (as well as challenge and security), co-worker relations, adequacy of resources, clarity of expectations about performance, promotion opportunities, and financial rewards.(5)

Health and Safety

In the areas of the company visited by the researchers, the principal positive effect of programmable automation on workers' health and safety resulted from the use of robots to perform some of the dirtiest and most hazardous work. In the paint area of the tractor assembly plant, robots now do much of the finish painting. In the foundry, robots perform some jobs formerly done by human workers, thereby reducing the exposure of human workers to workplace safety hazards. Also, various applications of programmable automation eliminate or reduce the amount of heavy lifting involved in jobs. For example, on the FMS, there is far less risk for back injuries and associated problems.

There was general agreement among workers interviewed about health and safety matters that the principal safety hazard associated with programmable automation was the risk presented by the complexity and unpredictability of automated systems. Working around complex machinery that could move in several different directions according to a plan that was not under the control of the operator or repair person--and may not even be well understood by those in the immediate area--was considered a very significant safety hazard by several workers. The level of complexity on programmable systems, particularly those that move material according to a scheduling program run from a remote computer, made it difficult for a worker to anticipate the system's behavior and avoid the risk presented by sudden and unpredictable motion. As an electrician at the tractor plant said,

> Automated machinery is made to go and stop on its own program. Sometimes you can shut a machine off to work with it, and sometimes you can't. Once you correct the fault, it's liable to kick off.

Another worker added:

> I've seen the thing move and nobody touched the button. You're dealing with something you can't control. It's created a whole different type of problem--not necessarily more problems, but different problems.

A major health problem associated with computerized automation was stress. Two major causes of stress on the job were mentioned: the intense pressure on operators and maintenance workers, discussed above, which is brought about by working with machinery that is complicated and highly capital intensive, and the stress of doing a repetitive job at a fast pace all day. Concerning the latter, a machine operator at the components plant said, "On my job, I know every move. It's like I'm programmed myself. It's the same thing over and over. That's stress."

Workers' Concerns About Displacement

Although interviews with workers focused on the work environment effects of programmable automation, almost every worker interviewed raised the issue of the displacement caused by the introduction of computerized systems. The pervasiveness of this concern, even among workers who still have their jobs, suggests that this must be considered one of the work environment effects of programmable automation. As one worker put it:

> We've got 4,500 people laid off. We've got some people that'll never be called back to their jobs. And part of it is because through the new technology there isn't the need for the amount of manpower as there has been in the past. Therefore you've always got in the back of your mind, well, am I gonna be next? You take that on top of worrying about whether your plant is going to be the next one to be shut down. Overall, when you start compounding it with everything else, I think it puts a lot of stress on what I call the average worker.

The change and uncertainty produced by the introduction of computerized automation, in addition to making workers concerned about the prospect of being laid off, gave an extra impetus to the interest workers frequently expressed in having more training on advanced computerized machines. As an operator who had bid onto the FMS said,

> I can see the handwriting on the wall at [this company]. In my estimation, in 10 years from now, maybe less, if you can't run a tape machine of some kind, you're gonna be looking for a job. Because the days of beating it out manually, they're gone.

FMS operators interviewed said that a chief reason why they had been interested in working on the new system was concern about their future employment.

Workers concerns also went beyond their immediate concerns for their own jobs. They were apprehensive about the effect that widespread automation would have on national employment. "What's the point of making cars with robots if there's nobody who can afford to buy them?' was a sentiment frequently expressed in interviews. An operator on the FMS said of the system, "It's a good system. But I would hate to see every plant in the United States going that way. What are your kids going to do when they grow up?"

VIII. CONCLUSION

Beginning in the early 1970's the company, a midwestern manufacturer of agricultural implements and construction equipment, began the installation of a wide variety of computer-based systems throughout its manufacturing facilities. Spurred by an increase in the demand for its products, the company took advantage of the need to expand its manufacturing capacity by investing in a wide range of programmable systems. In making these investments, the company was seeking several things: to increase its flexibility and its ability to respond quickly to changes in market demand; to promote greater manufacturing efficiency by improving the "flow" of material through the organization; and to improve managerial oversight and control of the company's operations.

The work environment effects of this major transformation fall into four broad categories: 1) effects that are the intended result of management's desire for flexibility, rapid response, and closer managerial control of operations; 2) effects that stem from the implementation process, broadly construed: that is, those that result from bugs in the system, the novelty and unfamiliarity of the system, and the elimination, creation, and restructuring of jobs; 3) changes in the work environment brought about by the complexity and highly-integrated character of these capital-intensive installations; and 4) the effects of systems designs that attempt, with varying degrees of success, to minimize the necessity for operator intervention.

Programmable systems allow the company access to far more information about the details of the manufacturing process than was previously available, from the number and exact location of parts produced on a certain day to information about how employees spend their workday. Some of this information was available when manual methods were used, but is now more readily accessible. Other information is now being gathered for the first time, allowing the company, for example, to track parts all the way through the production process, not just at selected points. This makes shop floor operations increasingly visible to middle- and upper-level managers, facilitating scheduling and making it increasingly possible to dictate the details of production from a higher level in the organization.

The result for the work environment is decreased autonomy for workers and their supervisors. The Terminal Labor Reporting System, which collects data on workers' production, downtime, hours of work, and so forth, allows the company to monitor production methods more accurately and more readily. For some workers, this close monitoring raises fears about how the information might be used by the company. It also is more difficult now for supervisors to bend the rules in their departments, even when this might benefit rather than hurt production. Overall, the ability of management to oversee the production process more easily and in greater detail enables the company to ensure that workers and supervisors operate "by the book" to an extent that was not possible before. This helps to standardize production, contributing to the predictability and control desired by management. In the hydraulics plant, many workers experienced this narrowing of their autonomy as unduly rigid, and felt that the operation had become "machine-oriented," as one worker put it

From the company's point of view, the improvement in scheduling that had come with the implementation of computerized management information systems benefits workers as well as management because it improves the flow of production. It also ensures that, as often as possible, there will be work available for workers, especially those on incentive pay whose paycheck depends on a smooth flow of work. While the company says that improved scheduling in the hydraulics plant has meant that there has been little or no downtime on many assembly lines because of part shortages, workers on stand-alone machines complained that the flow of work had become very erratic. At least some of this erratic flow, according to the company, is the result of the new-found ability to respond quickly to customers' needs. To the extent that this is true, the fluctuations in the availability of work are not a debugging problem but a consequence of business decisions made possible by the new system.

Implementation-Related Effects

Based on the research team's visit, there is strong evidence to suggest that the implementation and debugging process for highly complex and integrated computerized systems is far more prolonged than is generally realized. Almost 2 years after it began full operation, the FMS continues to require the "tender loving care" of operators, in the words of the project manager. More than a year after the opening of the tractor assembly facility, workers describe frequent downtime and the fulltime presence of maintenance personnel near certain systems. Given the complexity of the systems involved, it is understandable that problems would remain long after the initial installation; yet the persistence of such problems for a period of years, not just months, suggests that their effect on the work environment must be given serious consideration. The length of the debugging process, combined with a high rate of technological change (if indeed this continues at the company), points to the possibility that the debugging of one or another system could become a permanent fact of life--and of the work environment--at technologically advanced companies.

Several effects of the implementation process on the work environment were reported by workers from various parts of the company. One of the most striking was the frequent unsolicited mention of workers' desire for supplemental training. Workers who operated or repaired computerized systems universally felt that they were insufficiently prepared for work on the systems, and were therefore far less effective in their work than they might be. Along with the desire to learn more about programmable systems was a genuine interest, on the part of many workers, in the systems themselves and how they function. Most workers found the new systems interesting and challenging, and many, such as the FMS operators, were working on the new systems because they had specifically bid on the jobs.

Workers also expressed concern about the displacement caused by the introduction of computerized automation. Even for those who had not been laid off, displacement was an important issue, and thus an important feature of the work environment. Only workers with many years of seniority felt confident that their jobs were not in jeopardy, and some of the interest in trying to learn the new programmable systems came from the belief that only those with an understanding of the new machinery could be confident about their future employment.

Yet another effect of the implementation of new systems on the work environment was the disruption caused by downtime and scheduling irregularities that resulted from bugs in the new systems. Workers at the company were particularly upset about these problems if they were paid on the incentive system, because downtime and the unavailability of parts both act to decrease workers' hourly earnings. Some workers believed that the systems would work smoothly given time, while others were more sceptical.

Effects of the Complexity of the Systems

All three systems explored for this study were very complex, highly integrated, and extremely capital intensive. This had a pronounced effect on the jobs of those who came in contact with the systems, in particular the maintenance workers charged with fixing the systems. For most maintenance workers, it was exciting and challenging to work on a computerized system because of its complexity, but this same complexity created considerable pressure as well. By and large, it was the task of diagnosing a problem, rather than fixing it, which has become more complex, since repairs to electronic circuits may in some cases call for no more than pulling and replacing the right integrated circuit board. Diagnosis, maintenance workers reported, required more collaboration among repairers than was previously the case, and collaboration between workers from different skilled trades was particularly needed.

Much of the increased pressure that maintenance workers complained of came from the combined effect of the high cost of the system and the "domino effect" that a machine or system failure could cause. Because many of these systems are highly integrated, a problem in one part of the system can quickly spread to others. For example, trouble in one part of the materials-handling system in the tractor assembly plant could shut down the whole line; because there is less possibility of correcting a problem manually, say by taking a forklift to get the needed parts, the pressure on repair personnel increases substantially.

Finally, some safety hazards stem from the complexity of the equipment and the associated uncertainty involved. Maintenance workers felt that the large computerized systems were unpredictable, perhaps because their very complexity makes it difficult for a repairer to anticipate exactly what the system might do at any given moment.

Effects of Designing to Minimize Operator Input

One of the company's purposes in installing programmable automation is to reduce direct labor and create a smooth "flow" of production, involving less operator intervention. This changes the role of the operator from one in which there is regular interaction with the machine to one in which the operator intervenes chiefly when a problem arises. This change is best exemplified by operators on the FMS; they have regular tool-changing and other preventive maintenance duties, but are otherwise expected to be alert to problems and to act to eliminate or minimize difficulties that may develop while the system is operating.

Among the benefits to operators of a system which is designed to perform a range of operations automatically are the reduction in physical labor and the cleanness of the system, both of which were mentioned by FMS operators. Because the system automatically loads the parts to be machined, this heavy work is eliminated for the operator. The coolant which bathes the parts as they are being cut vastly reduces the metal dust in the air, an ever-present problem on most conventional transfer lines.

One of the work environment problems mentioned most frequently by FMS operators--as well as by maintenance workers on other highly integrated and expensive systems--is the alternating boredom and pressure which characterize their jobs. When the system is running well, vigilance is required, since the ability of an alert operator to spot a small problem will prevent it from becoming a big one. Attention without intervention is hard to maintain, however, and operators complained that the job could get boring if things ran smoothly. When there are problems on a system, however, each minute of downtime is very costly, and the pressure to diagnose and repair a problem quickly, combined with the stress of working on a very complex machine, can create serious problems for operators. When there are frequent problems with a system, for example during the debugging process, the periods of high pressure may be frequent and prolonged. The overall amount of repair time will drop as the bugs are worked out, but the fact of having to alternate between periods of attentive inaction and periods of high pressure remains.

To the extent that highly automated systems are conceived of as operating with little human intervention, it may be that their design and implementation are such that they do not accommodate necessary intervention in an optimal way. Operators on the FMS, for example, expressed a desire for more training than they had already received. Clearly operators' input was necessary on the system, yet its design and the training of operators may not have been carried out in a way that acknowledged and accommodated human input in an optimal way.

FOOTNOTES

1. The information contained in this section comes from the company's 1982 10K report, other documents provided by the company, and from a magazine article on the company.

2. Direct labor is defined as labor that is happening while a part is actually being produced. The running time of a machine tended by a worker would be direct labor, excluding setup, some tool changing, material handling, and maintenance.

3. Melvin Blumberg and Donald Gerwin, "Coping with Advanced Manufacturing Technology," presented at QWL and the 1980s, Toronto, Canada, August 30-September 3, 1981, p. 6.

4. Ibid., p. 5.

5. Donald Gerwin, "Do's and Don'ts of Computerized Manufacturing," Harvard Business Review, March/April, 1982.

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FOOTNOTES

I. INTRODUCTION

The site of this study, a commercial aircraft manufacturing division of a larger aerospace corporation, is widely regarded as being at the cutting edge of both product and process innovation in the industry. Many of the computerized design and production technologies that are now being introduced throughout manufacturing have long histories at the division. In the late 1950's, for example, numerical control (NC) machining was introduced; in the early 1960's the APT programming language, computer-aided design (CAD), and a range of main-line business systems were deployed; and in the early 1970's, interactive computer graphics was installed. Because of its extensive and pioneering role in the development of many programmable technologies, the division is an excellent location for a case study of their work environment effects.

The aerospace corporation is composed of a number of principal divisions: the commercial aircraft manufacturing division, the military airplane division, an aerospace group, and a computer services company. Overall, the corporation now employs about 80,000 people throughout the United States, with 40,000 in the commercial aircraft division. At its high point, this division contributed about 80 percent of the company's sales, but this figure has now fallen to about 50 percent, given the depressed state of the commercial airplane market. Most of the employment in the division (referred to hereafter as "the company") and most of its manufacturing facilities are near a west coast city. The principal sites visited for this study were plant A, where the three commercial aircraft, Beta, Gamma, and Epsilon, are assembled and where a number of design and manufacturing operations take place; the Plant B fabrication complex, where the majority of NC machining takes place; and an engineering center.

In exploring programmable automation at the company, this study has a dual focus. One focus is the use of computer technology to revolutionize the organization of work, from the design of the airplane to the machining and assembly of its parts. The goal is to define, streamline, and control the flow of information, fundamentally altering the way the company does business. In particular, this revolution is transforming the character of occupations in design, engineering, and other white collar areas. Many of the most striking changes are now in the process of implementation.

But the company also has an extraordinary diversity of existing computerized machines and systems, many of which have been around for decades, scattered throughout its operations. The second focus of this study is on one of these mature technologies and its work environment effects. The research team chose numerical control because NC has over two decades of shop floor usage and is a particularly important technology in aircraft manufacture. The problems and possibilities associated with NC go beyond any startup effects and may be generalizable to the application of other programmable technologies throughout the company. Moreover, NC is also directly affected by the organizational changes that are taking place. It is the production terminus of a stream of data that flows from design to the manufacture of a part.

This case will first discuss the research methods employed, and then analyze the economic context in which the company finds itself. The body of the case is divided into two basic sections: the first analyzes the broad organizational implications of programmable automation, principally computer-aided design; the second looks at the issues raised in the NC machine shop. A short section then discusses the emergence of technology as an issue in collective bargaining. Finally, a conclusion summarizes some of the basic issues in the case.

Some of the principal findings of the case study are:

- Programmable automation leads to an integration and increased interdependence of functions throughout the organization.
- An integrated data stream is being developed at the company that is intended to drive creative decisionmaking to an earlier point in the design/build process. Frequently, this is synonymous with moving decisionmaking higher in the organization. Small design-build teams of engineers will make the basic decisions and this information will automatically flow throughout the organization.
- For engineers upstream, CAD promises more creative and broader jobs.
- Many of the remaining jobs downstream will be less creative, more boring, and possibly more stressful.
- Those jobs primarily concerned with the transfer of data between groups will be eliminated by the integrated data flow. For a given amount of work, 30 percent of the work force not involved in the direct construction of the airplane could be affected.
- On the shop floor, electronic monitoring of machine functions make production operations increasingly visible to management.
- There is decreased latitude in shop floor decisionmaking; as a result, boredom has become a central concern of NC machinists.
- As a result of worker apprehensions concerning the rate and consequences of technological change, technology is emerging as a central collective bargaining issue.

II. METHOD OF STUDY

The fieldwork for this case was conducted during an 8-day visit to the west coast in April 1983. Before the arrival of the research team, contact was made with the company and with the two major unions at the research sites, the International Association of Machinists and a professional engineers' association. Both the company and the unions were very cooperative, allowing access and arranging the interviews that form the basis of the analysis presented here.

At the company, a series of interviews had already been scheduled when the researchers arrived. Interviewees were selected by the company management based on the researchers' request for interviews with a wide range of managerial personnel, from higher-level management involved in the implementation and management of computerized technology to first-line supervisors in production departments where programmable automation was in use. These interviews were supplemented with additional interviews arranged at the request of the research team during the 5-day visit to the company. All interviews with members of management were conducted at or near the worksite of the particular manager or supervisor, with a member of management present who acted as host to the research team.

Interviews were open-ended, and their structure was based on an interview guide prepared before the start of the visit. The actual content of each interview was tailored to the particular individual being interviewed, based on his/her role in the company. Interviews varied from one-half hour to several hours in length. In some cases, a tape recorder was used, and all lengthy quotations which appear in this report are transcribed from taped interviews. A few of the interviews were preceded or followed by prepared presentations outlining the features of a particular computerized system or technology-related issue at the company. Followup interviews, where necessary, were conducted by telephone, and additional written material was obtained from the company. Company sources were also supplemented with written material available elsewhere.

Interviews with union members were conducted through the auspices of the two unions. Interviewees were chosen by the unions, based on general guidelines set by the research team. The researchers asked to interview members of the bargaining unit who were affected by new technology, particularly engineers affected by the use of computer-aided design, and machinists and other workers (such as inspectors, programmers, and layout workers) affected by computerized technology, especially NC. Because of the way in which interviewees were selected, the workers interviewed cannot be viewed as being a randomly-selected sample of all workers at the company. While some attempt was made to ensure that a range of views was represented, the intention of the researchers was to capture a sense of the variety of reactions to programmable automation in a few selected work areas, rather than to assemble a "representative" group.

Interviews with union members were conducted at or near the union hall, and were, like the interviews with managers, open-ended. Again, an interview guide was used, and the specific questions adapted to the particular employees interviewed. Most interviews were group interviews, and all were tape recorded. Generally interviews with union members lasted for 1 to 2 hours, depending on the size of the group.

In total, interviews were conducted with 14 members of management, 4 first-line supervisors, 6 engineers and technicians, 38 shop floor employees, and officers of both local unions, including the presidents.

Overview of the Aircraft Industry 1970-1983

The aircraft industry is the second-largest employer in manufacturing in the United States. According to the Aerospace Industries Association of America, the industry was a major positive force on the U.S. balance of trade: "The 1981 aerospace trade balance, best among the U.S. manufacturing industries, was $13.1 billion, up from $12 billion in 1980."[1] In 1981, aerospace exports were 7.7 percent of total U.S. exports, the bulk of which were civilian products.[2] The most volatile sector of this industry is the commercial transport sector. During the 1970's, both the industry as a whole and the commercial transport sector in particular experienced extreme fluctuations in demand, leading one firm to the edge of bankruptcy and seriously affecting the financial health of the others. This section is in two parts: the first describes the commercial aircraft manufacturing portion of the industry in the 1970's, and the second analyzes the company's performance over that period.

Aircraft Industry

Although the industry is oligopolistic in structure, it is extremely competitive and innovative. The rewards and risks associated with producing a successful airliner are considerable, with each new design being profitable only if more than roughly 400 are produced and with market conditions that change too often to allow accurate prediction of future demand. These risks are great enough to force a company to leave the industry if it loses even one battle. During this period, one of the company's major competitors left the market due to heavy losses from the poor sales of its wide-body jet.[3] Major influences on the aircraft industry in the 1970's were:

-- energy prices. Aircraft that were designed before the oil price increases in the early 1970's were not as fuel efficient as later costs demanded them to be.

-- defense spending. Often a production line was kept open or kept at a profitable production rate by timely military contracts.

-- Federal regulations. New noise requirements spurred the purchase of new aircraft.[4]

-- the Export-Import Bank. This bank provided the leverage needed to make the aircraft industry the largest exporter of manufactured goods in the 1970's.

-- recessions in general. Commercial aircraft sales were often cancelled or stretched out by the airline industry due to the effects of recessions on air travel.

In 1970, all major segments of the aerospace industry were contracting. Orders for the Vietnam war were falling, the space program was winding down, and the demand for commercial aircraft declined due to recession and the change to production lines for wide-body airliners.[5] Most aerospace firms survived with a variety of government contracts.

By 1974, commercial aircraft sales were growing rapidly in spite of fuel price increases, although almost all of this growth was due to foreign sales of U.S. aircraft. Defense orders continued to increase, with major outlays for the MX missile, B-1 bomber, and other programs beginning.[6] The commercial aircraft boom continued until 1976, when there was a sharp economic downturn. However, this did not effect the industry as severely as the downturn in the early 1970's, as military and space orders were increasing over this time.

After bottoming out in 1977 at sales of $3 billion, the commercial transport industry reached $4.9 billion in 1978, over $8 billion in 1979, and peaked at $10 billion in 1980 and 1981. Due to increases in domestic air travel, much of this growth was due to U.S. airlines buying newer aircraft rather than growth in exports. At the same time, the defense portion of the aerospace industry was growing rapidly, leading to shortages of skilled labor and delivery backlogs.[7]

By 1983, all this had changed again. While defense orders remained high, the commercial aircraft market had collapsed, and was facing competition from Europe. Due to the increased difficulty of financing new aircraft sales, one major competitor was leasing aircraft that it could not sell; another had withdrawn from the market altogether, and the market share of the company dropped even as the size of the market dropped.

Europe's Airbus, which had slightly better financing terms, held on to most of its smaller market share over this period. There is little prospect for immediate improvement in the commercial transport market, but new product activity at both remaining companies in the industry "is brisk as these companies position themselves for a turnaround in the 1984-1985 period."[8]

Much of the hope for a boom in the 1984-85 period is that many of the aircraft currently held by the airlines are becoming economically obsolete as they age and are operating in environments for which they were not designed (high fuel prices and pollution and noise standards). The long-run effects of airline deregulation are ambiguous, but some in the financial community feel that the short-term effects have been harmful to the commercial air transport industry. Due to lower profit margins as competition has increased, airlines have not had the revenues necessary to finance the purchase of as many new jets as they would have had if deregulation had not occurred.[9]

The Company

The company had an interesting decade in the 1970's. It had been in a race with its two major U.S. competitors to build the first wide-body airliner, which it won with the introduction of the Delta jet in 1969. The introduction of this aircraft, however, coincided with the collapse of the commercial aircraft industry in the 1970-71 recession and with congressional cancellation of a large aerospace program. Throughout the remainder of the decade, the company had both good and bad fortunes, but the trend was basically upwards from the early 1970's. For most of the decade the company was the leading exporter from the United States and a major military contractor.

The company's market share, while consistently the highest in the industry, experienced extreme fluctuations during the period. For much of the period the company's share was over 50 percent (in 1980 it sold 73 percent of commercial jet transports in the noncommunist world), although in more recent years its market share has been declining slightly due to changes in production lines and competition from the European Airbus. (In 1981, the company claimed 56 percent of the market, which declined to 48 percent in 1982.[10])

The Delta, the company's most advanced aircraft of the 1970's, sold very poorly in the beginning of the decade. Approximately 400 of these needed to be produced to cover development costs and earn profits; by 1971 only one-third of this needed production run had been completed, and in that year only three more were ordered.[11] Through at least 1974, Delta sales were mainly to nondomestic buyers, partially due to the Export-Import bank offering better financial arrangements to foreign purchasers than were available to domestic ones. Although this aircraft later became a commercial success (by 1983, 606 of them had been sold[12]), the company did not know in the early 1970's if it had misjudged the market trends for new jet transports. This sort of experience is typical in the aircraft industry, but the company's risks have turned out to be fruitful ones.

The company's main source of revenues in the 1970's was the Beta jet, a narrow-body airliner that began production in the early 1960's. A number of versions of this aircraft were offered with different seating capacities and later with increased fuel efficiency. By the end of the decade around 1,500 had been sold, making it one of the more successful ventures in the company's history. Many of the production details of the more recent Epsilon jet are based on those of the Beta, so that the learning curve from the production line of the Beta can be transferred to the newer aircraft. The Beta production line is now being phased out.

The company is now banking its future on two new jets: the Epsilon and the Zeta. Although the jets are of different sizes, and are aimed at different markets, they have much in common. According to the company's 1982 Annual Report, 60 percent of the significant line-replaceable items are the same for both airliners. The Epsilon, however, has a seating capacity of 143 passengers, while the Zeta seats 220. The Epsilon is also intended for routes that need less capacity than the Zeta. Both of these projects are more international in scope than the company's earlier jets, with roughly 15 percent of their production taking place in Japan and Italy. This is due partially to a desire to spread the risk of these projects over other producers, partially a method of penetrating foreign markets more effectively (via less import restrictions), and partially a way for the company to limit its own capital investment. It is also a way of limiting its hiring; the company wants to avoid repeating the massive hiring boom of the late 1960's and the bust of 1970-71, when employment for the entire corporation skidded from 105,000 to 38,000. The method chosen to accomplish this is to subcontract more of its work to other locations so that its own work force can be stabilized. The company claims that the latest economic downturn will not have the adverse effect of the earlier one because the company accounts for only 10 percent of the local work force today, as compared with 19 percent in 1968. Since the local unemployment rate is 10.5 percent, however, rising layoffs by the company will no doubt still have a large local impact.[13]

III. COMPUTER-AIDED DESIGN (CAD) AND THE STRUCTURE OF WORK

The hardware, software, and forms or work organization utilized in computerized production at the company are changing very rapidly. As a result, the direction of technological development is a key determinant of how computerization affects the work environment. A snapshot of existing automation, even one focused on state-of-the-art installations might provide an accurate view of what exists today, but would give a static and misleading impression of a rapidly changing situation. In addition to the rapid pace of development, an important dimension of programmable automation concerns the use of computers to tie together disparate parts of production, thereby transforming the way business is carried out. Given this increasing integration, the scope of the study is critical. By concentrating on individual systems alone, it is all too easy to miss the forest for the trees. Consequently, this section focuses on the direction of technological development at the company with a scope broad enough to include some of the major organizational changes in design and production.

CAD--A Definition

Computer-aided design (CAD) is a central tool in most of the technological and organizational changes at the company. CAD is defined quite broadly as the use of computers to generate and evaluate designs, drawings, and other information throughout product engineering and manufacturing. Its use began in a major way on the Beta airplane in 1960. After steady increases over the years, there was an explosion of CAD applications on the Zeta and subsequent Epsilon aircraft in the late 1970's. On the Zeta, 35 percent of the engineering drawings were computer assisted, accounting for about 80 percent of the structural weight of the airplane. This percentage went up to 45 percent a year later on the Epsilon. Several thousand engineers and technicians have now been trained to use about 300 different terminals.

There is an extraordinary variety of systems scattered throughout the company, so it is difficult to generalize fully about their capabilities or effects. These systems can be divided, however, into batch, interactive computer graphics (ICG), and data base management. Batch systems, the first CAD systems, require that a designer feed information into the computer as a unit. After processing, the data is returned to the user. These systems rely on APT, an NC programming language, to define the geometry of parts. APT is then combined with other computerized design aids for a range of design and analysis functions. One powerful batch system is the company-developed parametric design or Batch CAD. A designer can use this approach when designing a "family" of similar parts, such as airplane wing ribs. In the past, drafters had to draw each part separately. Now the engineer develops a basic program for a typical part and then modifies that program, say with different dimensions, to produce the remaining parts. In contrast to batch systems, interactive computer graphics allows a designer or engineer to "talk" to the computer through a keyboard or light pencil and receive immediate feedback on a cathode ray screen. On the most advanced systems, the engineer can construct three dimensional solid models that can be rotated, enlarged, cross sectioned, and manipulated in countless other ways, all in a stunning range of colors. Finally, data base management systems are used to manipulate information, which may be in different data bases, to perform a variety of computer functions. These management systems in effect allow communication between separate computer systems.

Another way to look at CAD is by the functions it performs. Generally, there are four basic activities: geometric modeling, analysis, testing, and drafting. No single system, however, necessarily has all these capabilities. A geometric model represents the size and shape of the part in computer-readable form. Many design and manufacturing groups use the model as a point of departure for subsequent activities. Once engineers define the geometric model, analysis functions include calculations such as moments of inertia, weight, volume, or kinematics (the branch of mechanisms that deals with motion). An airplane is replete with engineering challenges in this area: wing leading and trailing edges, nose and main landing gears, rudder and elevator, and a variety of system controls. Complex surface clearances, difficult to detect manually, are easily seen through kinematics modeling on CAD. One of the most potent techniques is finite element analysis. The computer analyzes stresses, deflections, and other structural characteristics. If there are undesirable readings, the model can be instantly modified and reanalyzed. The most sophisticated type of analysis is the system model which utilizes a mathematical representation of the entire structure. After analysis, test systems can evaluate how a component or even the entire airplane performs under load. An engineer can see how a structure bends, rocks, and twists as simulated vibrations or oscillations are applied. The actual motions can be exaggerated and the action slowed so the engineer can pinpoint sources of excessive vibration and refine the structure design. Finally, CAD can considerably speed the creation of drawings. Once designers geometrically define the part on the screen, dimensions as well as other symbols can be automatically added. If needed, a paper copy can be reproduced on a plotter.

CAD/CAM Integration Team

A central thrust at the company is the linking of dozens of separate design, business, and manufacturing computer systems into a centrally directed, integrated whole. Aside from the technical incompatibility of many of these systems--an inability to "talk" to each other--a further problem is the lack of common procedures, agreements, and data standards throughout the company. This lack of coherent policy limits the effectiveness and expansion of programmable automation. A number of groups have been set up by the company to remedy this situation. The most important is the

CAD/CAM Integration Task Force, established in the summer of 1982 with a mandate "to expand the use of CAD/CAM for those applications where we have known capabilities." One hundred and forty people are directly involved in the team, which is directed by Mr. Smith, the director of manufacturing support for the Delta/Zeta Division, and Mr. Jones, the director of engineering design for the company. The team's tasks are presently scheduled to continue through 1984.

The task force began by evaluating a number of comprehensive studies concerning computer usage that were done after the Delta, Epsilon, and Zeta airplanes were built. Many task force members were surprised at the comparatively small use that was made of available programmable technologies. The information from the studies was distilled into 1,000 problems or "missed opportunities," as Smith put it, which in turn were sorted into 100 specific packages to be acted on. Moreover, the task force sought to select the current best examples of CAD/CAM at the company and see how they might be replicated. One method now being used to diffuse these models is the creation of detailed design-build handbooks that codify existing information and are usable as data resources. These handbooks will then serve as the basis for common agreements and procedures between various engineering and manufacturing groups. Aside from its formal mandate, the role of the task force as a clearinghouse for the best CAD/CAM ideas has already resulted in significant informal changes within the company, as managers and engineers review their current practice and contemplate alternatives.

Data Flow

Under current practice the data that describes the airplane's design and the subsequent information that determines how it is built are constantly being regenerated by the different groups that use it. The problem is not necessarily the lack of automation. In some cases, highly automated computer systems are incapable of communicating with each other. Many of these systems proliferated in response to specific problems and often were developed independently. As each individual system became more sophisticated in performing the task for which it was designed, it often grew less compatible with related systems. Within any system, there may be ample data processing capability and unrestricted information flow, or vertical automation. The roadblock, however, is transmitting that information to another group, or horizontal automation. Computerized design data, for example, are often converted into drawings which must be reinterpreted by other test groups or the production groups that actually build the airplane.

The constant re-creation of data is time consuming, error prone, and expensive. The noise group, for example, may be able to process data very rapidly once it is entered into the computer, but the group is now compelled to manually load the data from the design group. One analysis group recently purchased a high-speed computer capable of running a simulated wind tunnel flow on a wing section in 4 hours. This offers considerable savings over previous methods in which a prototype model had to be built. In addition, it allows more iterations to find the optimal design. However, 30 hours are required to load the geometry into the system.

In some areas, better data availability already exists at the company. The CAD/CAM integrated information network (CIIN), for example, is a large and complex data base that was used extensively on the design and manufacture of the Epsilon and Zeta aircraft. The system is advanced enough to allow the transfer of mathematical models between five major subsystems. It has, however, some major limitations. CIIN is basically superimposed onto existing operations, translating information from the original system into a common language and then retranslating it into a language usable by another system. While data are shared, the systems themselves are far from integrated. As a result, CIIN is complex and often cumbersome to use. Moreover, some key systems remain incompatible and therefore cannot be coupled in. Mr. Grey, former director of computer systems at the company, maintains that each individual system retains all its former limitations.

> Each CAD/CAM system had its own unique user interface, and most user interface languages were not convenient. High skill requirements in low level computing techniques, computer language, and jargon forced the end-user to deal with computers through "software specialists". Furthermore, prolonged training and slow learning curves were prevalent, and retraining was required for workforce reassignments. (14)

The task force believes that the detailed analysis necessary to effectively apply automation has not been done and views this as an important part of its work. The computer has simply been applied to automate a given manual function, instead of analyzing what a task consists of and why it is done, thereby questioning the process itself. Speed has been gained in moving between functions when the functions themselves may not be necessary. It is the equivalent, according to the task force, of automating files before considering whether the records have to be kept at all. According to Mr. Jones:

> When you introduce computers into a particular organization, the tendency is to replicate the manual method of doing things, the way you've been used to. You gain some productivity from that because you speed up the flow of data. But that doesn't look at how you want to handle the information and how you want to handle the interfaces when you move from organization to organization.

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Organizational Impacts of Controlled Data Flow

The initial attention of the task force was directed at securing more uniform procedures and data agreements throughout the company in order to expand existing applications of computer technology. Some key task force members, however, soon felt that major productivity gains could be achieved by defining, streamlining, and controlling the flow of information. CAD would be the port of entry into the system for design, geometry, and other information. Because computerized equipment would be used to develop the design, that design would be encoded in a standardized and computer-sensible form, ready for launching into an electronic data flow that links all data users in the organization. Moreover, manual transmission of data would be eliminated as long as computerized linkages existed between the CAD system and the next information user.

The end result would be a controlled data flow in which various groups might enhance or refine the data but would not recreate it. Downstream from design, for example, the appropriate information for production operations would be added to the basic design data. Mr. Smith sees these organizational changes, rather than any specific hardware, as the most significant use of new technology at the company.

The establishment of a controlled data flow fundamentally alters the way the company does business. The changes are so far-reaching that Smith stresses they will be revolutionary rather than evolutionary in their impact. While the flow of information is as important on the shop floor as in the office, the emphasis of controlled data flow is on "non-touch" labor--people who do not add hardware directly to the airplane. At the company, people directly employed in "hands-on" manufacturing comprise only about 1/3 of the work force. Because of the low level of rationalization that has taken place among non-touch labor, it presents a promising target for computer supported reorganization, according to the task force.

The use of a computer technology to integrate the flow of data does not in and of itself determine the form of work organization. The computer is a powerful tool, but only a tool, to carry out managerial decisions in this area. There are a number of alternatives for structuring the data flow and the decisionmaking process. Underlying all of them are the increased possibilities for communication and coordination that computers permit. Beyond this, however, some organizational options stress more centralized authority over basic design and manufacturing decisions, while other options move toward more decentralized responsibility. In many cases, the technology offers a choice as to where in the organization a decision should be carried out. For example, detailed production decisions such as the speeds and feeds of the machine tool used to produce a part can be set by a design engineer, a part programmer, or a machinist. In other cases, the option exists to fully automate the job, particularly those occupations where the primary task is loading or unloading data from other groups. The work environment effects of programmable automation are heavily dependent on the character of these organizational choices. Simply looking at the social effects of the hardware or software is therefore inadequate.

The research team found three principal organizational impacts deriving from the company's plans for the future integration of CAD and CAM:

-- A drive to move creative decisionmaking as high in the organization as technically possible. Smith described this as "putting the smarts up front." Small integrated teams will make the basic design/build decisions early on and then everyone downstream will process a much more fully-defined set of data in a more constrained way.

-- The limited latitude for downstream decisions leads to tighter, more uniform standards for communicating ideas and carrying out projects.

-- The increased predictability and reduction in the amount of data input and output make the full automation of a considerable number of jobs likely. Smith believes that for a given type of work, the "hands-off" labor force could be reduced by 30 percent on new projects.

These profound changes can be carried out with a minimum of new technology in the near to medium term. The key is the reorganization of the work and the application of existing technology. As Mr. Grey put it:

> One of the hardest tasks in establishing an effective data base has nothing to do with computers, but rather with revising company procedures. All procedures must be reviewed for possible changes to make them support automated data transfer. (15)

Transfer of Creative Decisionmaking: Smith describes the current organization of production as one in which knowledgeable people with hands-on experience make decisions at various levels and are tied together with paper. He comments that "everybody adds their thoughts. Everybody is innovative so you've ended up with a product that is touched by a lot of people." Automation to date has principally concentrated on controlling the paper links, but the task force seeks to utilize a computer-controlled data stream to organize this knowledge up front and optimize the number of links. Utilizing CAD, the geometry of the airplane is mathematically defined, electronically encoded, and then launched for use on downstream operations. An increasing number of manufacturing decisions will also be made at the level of design, so the initial release of data can be more complete and the autonomy of further operations reduced. This integration requires the product designer to have a better understanding of the entire manufacturing process and an awareness of how the data will be used in other areas. Moreover, the designer will be joined by production engineering, tooling, manufacturing research and development, and other disciplines in small design-build teams. A central part of their responsibilities will be delineating the data flow. Smith visualizes "a lot more educated decisions being made by a smaller group of people in very close knit collaboration." The corollary of this is less latitude for anyone who subsequently receives the information. He continues:

> Once the system is in place, most of the decisions are made so you're taking away a lot of individual decisions....whoever's involved downstream is working in a lot more controlled environment than he has in the past.

Putting more decisions up front results in a heavier dependence on management to define and organize the entire process. Program management will therefore require a broader technical background to exercise this increased authority.

Increased Standardization: Constraints on an engineer's ability to choose how a design is to be done serve to standardize operations and to reduce novelty in design. According to one engineer who formerly worked in design and now implements CAD/CAM systems:

> From where I am now on the manufacturing side, we don't want that design engineer to be creative up there. I mean unless there is some good reason to be. Because every time he creates some new part that is different it has to be planned and an NC program written, if it is going to be run on an NC machine....I am sure that it might affect somebody's creativity but I don't know whether an engineer is really supposed to be creative or not. The idea, I believe, for an engineer now is to just take a bunch of things that are out there and put them together into a whole and do something. It is just a matter of looking things up here and here and here and getting it together.

Some of the features already available on CAD technology support the move to increased standardization. At the company CAD offers engineers a library of already proven parts that can be plugged into a design at will. Also, some systems lead an engineer through the design process by providing a menu of options. This can result in an engineering problem being seen in a particular way. In the past, engineers had available books of "producibility tips" to select optimum designs for manufacturing; now these tips will be included in the software. The design engineer will then run the design against this software for the machine's evaluation of how "producible" it is. The engineer quoted above commented:

> The idea is to try and control the data and the system so that everybody does everything the same way. Consistency is one thing you get out of this because you have a system and you have only certain things available for people to use. They use those things and you get a much more consistent type of design.

Increased standardization requires tighter standards for communication. Members of the CAD/CAM task force, for example, identified the lack of adequate NC drafting standards. With CAD, however, Smith stressed that control of the data flow leaves less to individual option.

Job Elimination: The controlled data flow can lead to the total automation of some jobs in two ways. First, the constant stream of information makes superfluous those jobs that are primarily concerned with the input and output of data. Second, some operations still must be performed but they are now done either by someone else upstream or by the computer. Ironically, many of these jobs were created as a result of previous computerization efforts. Smith comments that the most noticeable effect of the reorganization is "to reduce people that are currently in the hands-off paper support roles. Either eliminate the need for the paper to flow through the support people, or if it does, the machine does some part of the data input." Another engineer elaborated on the role of expert systems:

> With some of these computer systems, if they can really get an expert system going, you don't necessarily need a high-priced engineer to do a design. You can say "here are my parameters, here's what I want" to the system and it comes up with the design for you. You tell it the general overall things that you are looking for and, if it has a good knowledge base that it is working from and if it has a good program, it theoretically should be able to do a much better job of the design than the engineer could. That program may be a combination of expertise of a number of different people, plus it has access to good parts and good data.

Any job is threatened whose primary responsibilities involve the transfer of data rather than its creation or augmentation. Occupations such as drafters, tool designers, tool schedulers and, in particular, manufacturing and industrial engineers are targeted. According to Smith:

> ...after initial production concepts are established, many manufacturing engineering and industrial engineering functions handle repeated data that can be done by the machine.

Smith feels that for an established project on which integrated data flow is applied, 30 percent of the total "hands-off" labor force could be eliminated. For some operations in production engineering, the percentage could be as high as 80 percent. These gains could be achievable on the next major airplane project.

Occupational Profiles

The themes of moving knowledge upstream, increased standardization, and full automation affect various occupational groupings in different ways. The following broad outline, developed out of conversations with members of the CAD/CAM task force, details some of the implications, contrasting existing practice with what is planned for the future.

PROGRAM MANAGEMENT

Today: Decisions are based on market analysis and the known resources of the company. Scheduling is based on experience and a lot of data. The program is limited to two or three iterations.

Tomorrow: Program management moves to a studied art. Judgement remains but it is informed by more data. The ability is there to play out alternative scenarios much more rapidly for decisions based less on "feel" and more on knowledge of alternatives. Twenty or thirty scenarios will be possible. More technically-skilled people will be required.

ANALYSIS

Today: Analysis has impressive automated capabilities within any given group but is not horizontally automated between groups. The individual groups of the technical staff--structures analysis, noise analysis, aerodynamics, flight controls, propulsion, systems, and weights--make extensive use of computers, but load and transfer data manually among the different staffs.

Tomorrow: More extensive horizontal automation as the manual work involved in transferring data between staffs is eliminated. There will be fewer people as "inputters and outputters" of data are eliminated, but more skilled analytical people will remain. The test organization, which is now as automated as any group in the company, will be tied into analysis for improved feedback.

DESIGN

Today: This is basically done manually with a lot of people making a lot of decisions.

Tomorrow: Design will initiate the data stream. There will be automated techniques such as graphics and parametric design. Additional tasks will be added to better define and more tightly constrain the information flowing downstream. Some of the functions formerly done by planning and tooling design will be taken over. Overall, the work output will increase with a stable work force. Some subgroups such as drafters will be substantially reduced.

PLANNING (MANUFACTURING ENGINEERING)

Production Engineering and Scheduling Today: This area has a basically manual organization of work in which computers are used to replicate and speed the transfer of data between people.

Tomorrow: A major reduction of personnel is anticipated in this area. People who remain will enhance rather than simply transfer data.

TOOLING

Design today: Design tooling is automated today, but must continue to do many operations manually because aircraft design is still manual and the geometry can't be obtained directly.

Design tomorrow: Tool designers will be part of a design team that will include product design, production engineering, and tooling. Key decisions will be made further upstream. There will be fewer people.

Build today: The construction of tooling is fairly advanced.

Build tomorrow: Fewer and better tools will be built, but the fundamental approach will not change.

MATERIAL

Today: Material is composed basically of input-output people who use computers to transfer information between them.

Tomorrow: Some people will remain to enhance the data that flows through, but there will be a sizable reduction of people and a large impact on the function.

INDUSTRIAL ENGINEERING

Today: This function is based on experience and subjective judgements. There is little iteration of possible alternatives because it is too time-consuming.

Tomorrow: Industrial engineering will become computer-assisted and very scientific. There will be a considerable reduction in the number of employees, leaving the more skilled.

FACILITIES (DESIGN, SUSTAIN, BUILD)

Today: Facilities is manual with little vertical computer capability.

Tomorrow: Much of this operation will be moved upstream to the design team with a considerable reduction in people.

MANUFACTURING RESEARCH AND DEVELOPMENT

Today: This is mostly manual today and focused on the build process.

Tomorrow: The scope of this activity will broaden to cover the entire design/build process. There will be more computer-assistance. Some functions will be integrated into the design team.

The CAD/CAM task force anticipates that the near-term changes on the shop floor will be far less dramatic than in the above areas of non-touch labor. While this may be true comparatively, it is the opinion of the research team that it understates the scope of some of the continuing changes in production.

FABRICATION

Today: There is already a considerable amount of computer capability in numerical control, computer numerical control, and direct numerical control.

Tomorrow: There will be more DNC but little direct effect on the person on the shop floor.

INTERMEDIATE ASSEMBLY

Today: This is a very labor intensive process.

Tomorrow: Many of these intermediate steps will be eliminated.

MAJOR ASSEMBLY

Today: This is also a very labor intensive operation.

Tomorrow: There will be little change in the short run.

QUALITY CONTROL

Today: This process is intensively manual.

Tomorrow: There will be a move from quality control to quality assurance (i.e., each department will have responsibility for overseeing quality as the component is produced).

CUSTOMER SUPPORT

Today: Customer support relies on manual work organization with a considerable amount of vertical computer assistance.

Tomorrow: Controlled data flow will reduce the number of people whose function does not enhance data.

VENDOR PARTICIPATION

Today: This area is basically manual.

Tomorrow: There will be considerable pressure for the vendors to automate and to become more directly a part of the data stream.

Developing the Integrated Data Flow

A central purpose of the CAD/CAM integration team is to expand proven technological applications by picking the best existing concepts and standardizing the approach for other areas. A precondition for this is the establishment of common procedures, standards, and agreements between different data users. The task force therefore conducted a search for relatively simple applications that could be used to test the new methods. By first testing these principles in straightforward situations, the results could be applied more effectively in more complex areas. As a result, the test applications involve two-dimensional rather than the considerably more complex three-dimensional systems. Three of these applications are the design of floor panels, sheet metal work, and layout of passenger accommodations (LOPA). One important sheet metal application is a two-dimensional programming and machining system called the graphics automated template system (GATS), which will be discussed in the programming section. LOPA will be briefly explored in the next section.

In many ways, the floor panel application has received the most attention. The interior for virtually every airplane is arranged differently according to customer specification, leading to a wide variation in the panels that make up the floor of the aircraft. The task force has created a series of "preferred" and "inactive" procedures for engineering design, engineering release, and operations. The inactive approach corresponds to current practice in most cases, for which the company is reluctant to use the term "obsolete." The "preferred" procedure is what the task force is seeking to implement. Today design engineering must manually pull together and coordinate layouts from the systems group and a considerable amount of data received piecemeal from the payloads and structures group. This synthesizing of data can cause considerable delay and error, particularly where changes are involved.

Benefits in the Design and Drafting Process

Elimination of routine work: CAD makes it possible to eliminate certain sorts of routine work associated with design and design changes, managers said. Some of the calculations involved in making relatively common alterations can be performed automatically or semiautomatically at a CAD terminal. The layout of passenger accommodations (LOPA) function illustrates the elimination of routine work. Most airlines have different arrangements of lavatories, seats, galleys, and other interior features. A change in any single feature may cause a considerable amount of rework as other elements of the design are modified to keep relationships constant. Interactive computer graphics is ideally suited to handle these repetitive adjustments. For example, if the seats are moved backwards or forwards the location of the oxygen masks must also be moved, which LOPA does automatically. The availability of LOPA allows more different arrangements to be developed for a particular customer, with eight or ten variations before final approval not unusual.

A member of the CAD-CAM integration team elaborated on the idea that CAD eliminated much of the drudgery associated with design work, freeing the engineer to be more creative.

> It probably gives [the engineer] more time to design as opposed to doing more of this stuff over and over again...The fact is that it takes the tedious work out of it. I should think that if you go to the engineer and say to him, "What happens if I twist this or I put a different dimension on it, what happens to these things?" The downstream domino effect--does he want to spend his days doing that when the machine gives him a tool to do it in minutes or hours? I should think that he would be happy to see the results of that...

Access to current design: Another advantage of CAD cited by managers and engineers is that CAD can make it possible for all engineers to have immediate access to changes in design made by any of the users of the common data. Instead of having to produce and circulate a new set of drawings, users of CAD terminals can modify the data sets to which all relevant engineers have access, making revisions instantly available to others in the company. According to several engineers, this eliminates much time spent searching for and verifying the latest drawings, as well as the time spent revising designs that were mistakenly based on outdated drawings. One engineer said:

> There was a definite effect at the time we implemented this particular system in that your ability to see the latest information was right there in front of you in an on-line system. Prior to that, if you were lucky, you were within 24 hours but that wasn't the average. We were usually several days behind in data play.

On the Zeta program, technology staff analysis had much earlier access to engineering information as a result of CAD. One consequence of this early access was a more effective monitoring of weight growth, a key factor in meeting airplane performance requirements. The need for costly after-the-fact programs in this area was therefore minimized.

Reduction in errors: The standardization and the ability to automate certain checking and verification functions which are part of using CAD systems were said to reduce the number of design errors that go undetected. A study done early in the Zeta program concluded that 24 percent of the major changes made were a result of basic engineering error. Many of these changes have to be done when the airplane is already being built, which is costly. An engineer, speaking of the benefits of using CAD systems, said that designs done on CAD were, on the average, better than designs produced using manual methods.

> I think one of the things that you see out of a computer-aided design system is that designs are much more accurate. You get a lot better design the first time. There aren't nearly as many engineering errors and changes that come about. You have libraries of parts that have all been worked out already, and if you use these parts in your design then you come out with a good product.

The increased coordination and better communication mean that errors are more likely to be discovered earlier, in the design rather than the manufacturing stage, where they are easier and less costly to fix. Mr. Green, director of computing and head of the Integration Team's steering committee, states:

> Every error has the potential to cause a lot of extra cost by the time we are able to spot it and fix it. If we don't catch that error until flight test, it is most costly of all. Even when caught on the assembly line, an error can be awfully expensive. (16)

Faster iteration: An advantage of CAD frequently cited by engineers and managers was the ability to revise designs more frequently and to experiment more fully with design alternatives. One of the heads of the CAD-CAM integration team described the effects of the ability to iterate more rapidly. He predicted that as CAD-CAM integration advanced, certain aspects of the design process would become less subjective because in the future judgement would be informed by a more extensive knowledge of the alternatives under consideration. The ability to "play out" the implications of a design concretely on the screen allows designers to operate with more information than they have had in the past.

Readier access to technical aids: CAD systems have the ability to provide access, through the system, to design information that can then be displayed on the screen. In this way it is possible for an engineer to review technical information of the sort generally found in design manuals without leaving the CAD workstation.

Physical movement: The frustration of searching for drawings and technical manuals is minimized by making the information that an engineer needs available through the system. One engineer described the change when a CAD system was introduced in a test area of the company.

> I think that CAD consolidated a lot of things that we had to run around the building looking for. Before, you had to go to the vendor drawings or files or search around on people's desks to find the information. You can find 99 percent of it now right in front of you on the tube.

Problems Associated with Controlled Data Flow

There are four principal dangers of moving towards a front-loaded integrated data flow:

- -- design originality becomes constrained in areas where it is of value.
- -- the system is incapable, given the near-term limits of the technology, of incorporating enough knowledge to perform in an optimal manner.
- -- the engineer is split further from the hands-on feel of the product and the realities of production.
- -- many of the remaining jobs in the data flow become less creative, more boring, and more stressful.

Less Originality: Bold and innovative new design departures could be precluded by an overreliance on optimized subunits which a designer pieces together to construct a new design. Rather than freeing the engineer from boring and repetitive work, this approach could establish subtle though effective new constraints. Mr. Snyder, a former company vice president for engineering, now on special corporate assignment, commented on the danger of overstandardization.

> If you carry it too far, you tend to suppress new ideas and new initiatives. You can build yourself a catalog of ideas and lose all initiative. We don't want to standardize on one landing gear to the extent that we don't give anybody the opportunity of building a better one. I guess I've got a concern about overreliance on the computer. We've got to keep putting new ideas in the front end. (17)

Generalized design rules may not be optimal in all cases. An example quoted in IEEE Spectrum discusses the design of the bulkhead for an airfoil. An engineer can simply insert structural supports with a light pen rather than drawing them on paper. But, by doing this, the engineer avoids thinking about bulkhead thickness or evaluating different positions for supports.[18]

An important assumption in the use of CAD is that the quantitative and qualitative aspects of design are fully separable. Theoretically, the human designer should do the qualitative and the machine the quantitative. Mike Cooley, formerly a senior design engineer and past president of TASS (Technical And Scientific Staffs), a British union of scientists, engineers, and technicians, points to the difficulty of accurately segmenting design in this way.

> The process by which these two dialectical opposites are united by the designer to produce a new whole is a complex and as yet ill defined and researched area. The sequential basis on which the elements interact is of extreme importance. The nature of that interaction, and indeed the ratio of the quantitative to the qualitative, depends in part on the artefact under design consideration. Even when an attempt is made to define the proportion of the work that is creative, and the proportion that is noncreative, what cannot be readily stated is the stage at which the creative element has to be introduced when a certain stage of the noncreative work has been completed. (19)

Need for More Human Input: Some engineers at the company feel that seeking to minimize human decisionmaking, either by driving it earlier in the design/build process or seeking to build it into the system, could lead to the atrophy of critical human skills. These engineers tend to be among the highest-seniority people in the work force. In their minds, many problems that are effectively solved today are solved because skilled people are still available even though their jobs seemingly require fewer skills. When unusual situations arise in the future, however, those skills may no longer be there. Smith describes some of the objections these engineers raise by quoting them as saying: "You guys are killing the very thing that has allowed you to sit down and think you're organizing the business, the creativity part." He then admits, "I'm sure they're partly right. They've been around too long to be wrong."

Severing of Design from the Product and from Manufacturing: A serious danger of driving creative decisionmaking upstream is the further separation of these decisions from the reality of production. The design engineer or even the design-build team, with little if any day-to-day contact with the actual way parts are fabricated, will have production reality filtered through the computer model. As a result, the engineer's frame of reference could become distorted. The ability to test 600 brackets on the computer rather than six brackets manually could prove to be an illusory benefit if the engineer has lost the feel for what a bracket does.

Some argue that the separation of design and production has already occurred. In their view, controlled data flow, rather than causing or exacerbating the separation, is a technological solution to it. The lack of manufacturing experience on the part of design engineers calls for increasing control over the engineer's ability to choose how a part will be designed and produced. Mr. Grey states:

> At one time communication between engineering and manufacturing functions was simple and straightforward. The drawing represented agreement between the two functions, and was derived from close personal contact between the designer, who conceived of the design and the mechanic, whose job it was to produce it. However, as products became more complex, more people became involved in the total process, and communication became more difficult. By the time the Delta airplane was developed, thousands of engineers and manufacturing personnel were needed and it was impossible for engineers to visit the shop or assembly areas to discuss the design intent. An additional problem was that, because of specialization of functions, people understood only the small portion of the airplane for which they were responsible, losing track of the whole project.(20)

Smith elaborates on how CAD is the solution to this problem:

> It's not surprising to me that we'd be going to a system that will discipline people to what data they can control and be sure that technically most of these other decisions are made for them. I think it's a very smart evolution.

Others interviewed also complained about a lack of manufacturing experience among designers. But, initial CAD applications do not seem to have relieved this problem. A lead in an NC parts programming area described the problem as he saw it:

> Some of the CAD-CAM types don't have the mobility or background to be able to look at an object with the perspective in mind that sometime it is going to have to take form as a hard piece of material or part...I found that sometimes we have trouble making this come together so that they understand what we need and we get them to understand what they have to do to give us what we need. I feel that if some of these people had the experience of maybe being down on a machine and having physically built some of these things at times it would help considerably.

One engineer elaborated that CAD offered no feedback as to whether the design was right or wrong:

> The difference between CAD and CAM is normally that the CAD guy a lot of times doesn't have the manufacturing experience to be able to put the right information into the system. I know I've seen that happen a lot of times where they are trying to design something but they haven't got any idea how the common sense part of it works.

Mr. Thomas, the manager of engineering computing systems, framed the problem of the contact between engineering and manufacturing somewhat differently. Instead of focusing on the absence of manufacturing experience among design engineers, he focused on the difficulty of getting information back from the shop floor to the designer's office.

> We want to make the full CAD-CAM linkup. One problem we've had is learning what the real manufacturing problems are and getting this information back to engineers.

A further danger is that the ability to test models on the CAD system will lead in the direction of building too few prototypes. An illusion could easily develop, given the extraordinary capabilities of CAD, that the model is reality. This will further drive engineers away from the subtle though critical interplay with the product itself. The costs of this illusion could be quite high in terms of the atrophy of key engineering skills.

Another issue related to the use of complex computerized systems and the role of skill in those systems was raised by an electrical engineer:

> One of the things that bothers me is, when you take a system that was designed by a family of 100 heads and keep changing it and you replace those people, pretty soon nobody knows what half the software does. That's one problem that I worry about as a user ...You almost have to retain somebody to be able to go in there and make that change. I don't know where that is going to put us in the future, that kind of bothers me. How big some of these computer systems get that you don't have anybody that knows enough about the system to make it keep working.

Quality of the Remaining Jobs: There is little question that senior jobs on the design-build teams will become more creative, broader in scope, and more challenging. But, what of the jobs downstream? Frederick J. Norton, the manager of the interactive computer-aided design facility for the electronics engineering department at the Lawrence Livermore National Laboratory, points to the possibility of increased stress and less job satisfaction:

> The first effect on the individual is the change in job content. An extreme example is where a drawing board is exchanged for a CRT screen. The act of design is inherently that of decision-making, but with interactive graphics the lower-level decisions are made by the machine. Two dangers exist. If previously one man performed both levels, the introduction of computer aids may remove the time when he previously let things mull over in the back of his mind. This may result in unacceptable high pressure on the individual. If, on the other hand, the two levels were previously separated between, say, senior and junior designers, the role of the junior designer may become an entirely clerical one, devoid of any decision-making content. This would result in considerable frustration if the task is still performed by a skilled person. (21)

Norton conducted a study of 100 CAD users in a number of companies, including the one under study here.22 Of this total, 27 users complained about mental fatigue and 34 about eyestrain. Forty-one of the users were apprehensive about learning to use the system. Some of the reasons they gave included:

-- dead-end job with very little growth potential (7)

-- dedicated to the system with lack of use of other skills (13)

-- lack of accomplishment (5)

-- lack of being creative (11)

The study reported a range of positive and negative comments about CAD. Overall, 81 people felt the growth potential of the new technology was better or far better than what had gone before. Some of the problems users complained about include:

-- shift work/deviated work schedule

-- it's you and your machine, no more time for social activity

-- older designers/engineers distrust the system

-- extensive use wears me out

At the company, Smith describes what could happen to some of the downstream jobs:

> A number of people that are left will be an element of a very controlled process. The ingenuity of the craft will have been removed. The advantage is to have more consistent outcome with the hiccups removed. People's actions will be more controlled by strict procedures. The human part of the job will be less evident.

Jones adds a more favorable dimension to this assessment:

> The ones that are left are the ones that are skilled at doing the right things and understanding why they're doing them. We're eliminating the routine part of it but enhancing probably a lot of these skill levels.

Additional Aspects of CAD

Interaction among engineers: CAD affects the amount and type of interaction among engineers. By its ability to pull together in one place a lot of disparate information, CAD ties the engineer more closely to the workstation. While there are clear disadvantages to spending work time combing the area for the latest prints, there may also be advantages. Searches for drawings provide periodic breaks from sedentary desk work and may also promote interaction among engineers, leading to increased communication and decreased social isolation.

The danger of restricted communication as a result of CAD is a real fear of some engineering managers. The engineering manager at another aerospace company spells out this concern:

> Innovation doesn't occur unless engineers talk to each other. In the old days--10 years ago--people used to sit in an open area, the electrical engineers not too far from the structural engineers. If you wanted to put a circuit through a bulkhead and you didn't know if it would affect the distribution of stress, you'd go over and ask. Now all that information is on the computer. (23)

An engineer at the company agreed that CAD reduces some conversations between engineers, but maintained that the necessary communication for important decisions will still be there.

> If this guy has a copy that he has received from this element in this system here two weeks ago, he doesn't have to call up and say, "Hey, have I got the latest copy or have there been any changes made to that?" The answer is automatic. Call up the data set and you have got it and if it hasn't changed, it hasn't changed. The fact is, though, that if you have a question about the design and you see that you run into a no-can-do, you still have to talk to them and say, "Hey, you painted me into a corner here. I can't live with it. Let's change the design." The communication will not go away. It will still be necessary.

Supervision and monitoring: Computerized systems present the possibility of electronic monitoring of engineers and operators. Most engineers at the company are already highly visible to their supervisors because they sit at desks placed end to end in rows filling up large rooms. Electronic monitoring potentially provides management with an additional check on an engineer's work, because records are kept on how frequently individual engineers use the terminals. One engineer, who said that the terminals in his area were monitored, asserted that the monitoring was done to determine how fully the system was being used, not to discipline any particular individual.

> You can look at a certain amount of time and you can count the number of transactions that are being done at that particular terminal. You can get an idea of how much activity is going on. If you log on by the person, you can look at the number of transactions that have been done by that person. As a matter of fact, the reason that it was done was not to monitor people; it was done to determine what kinds of costs should be assigned to different people because you get charged by your connect time.

This engineer believed that monitoring was motivated by the high capital cost of the equipment. This cost can create a pressure to produce, as well as a sense of being watched, that affects an engineer's experience on the job. The same engineer added:

> I would believe that once you get your own personal computer system that is all there, right there, and you have access anytime you want it and you know you are not sort of getting monitored, and the price is such that they don't have to monitor it that close, you are going to see a big change in the way that design is being done.

One CAD manager told the researchers that terminals were moved out of special rooms into the open work areas, in part, to better supervise what engineers were doing on them.

Familiarity with the equipment: Like any other tool, CAD is more effective in the hands of a practiced user. The frequency with which an engineer uses CAD affects both the productivity and comfort of the user. Infrequent experience with CAD equipment can become a real barrier to its use because the user will be relatively ineffective when using the system, and the stress caused by unfamiliarity will be greater. The differences between systems can also cause problems for engineers whose jobs require that they use several different systems.

The problem of unfamiliarity with the equipment can be reduced in three ways. First, more frequent use of the machine will serve to lessen the problems caused by inexperience. Second, so-called "user-friendly" software, which prompts the user and displays choices on the screen in English, can help to lead inexperienced or infrequent users through the system. Finally, access to training classes, or perhaps even more effective a person well-versed in the use of the equipment who can help with problem-solving, can help engineers to overcome problems created by unfamiliarity with the equipment. The Interactive Graphics Data Analysis sites, used by the Technology Staff at the company, have an on-site employee who supervises the use of the computer and assists engineers when problems arise.

Reliability of the equipment: Once design operations come to depend on the use of CAD equipment, the amount of downtime, both scheduled and unscheduled, becomes important. If the computer system is unavailable for a period of time, all work involving that system must cease. Because drawings in their hard-copy form have been eliminated, there is no possiblity of returning to conventional methods when the machine is not running.

Variations in response time of the machines also can cause frustration and stress, one engineer reported:

> - If you are used to ten seconds for something and it comes in ten seconds, you have no problem. If you are used to something coming back in a second or two and then it switches to ten seconds, it seems like forever. It really does. You get a concept of how fast this thing ought to respond, and when it doesn't respond in that amount of time you start getting agitated.

Effects on Skill

In terms of the effect of CAD on skill requirements, it appears that two opposing views exist at the company. Smith and Jones believe that as the company comes to be organized around a smooth flow of data, employees who do not "enhance" the data--which is to say, generally the less skilled--will be the ones eliminated. By contrast, Thomas believes that one of the advantages of CAD is that it allows less experienced people to do designs that before would have required very substantial amounts of experience. Describing CAD at the company, he said, "You don't need lots of expertise to use this system. A guy who was with the company for a year did a design that before would have taken someone with 15 to 20 years experience to do." From his point of view as a manager, he said, CAD has distinct advantages: "You store the knowledge you've built up over years of experience and you can apply it with a less experienced work force."

These two views are not as incompatible as they may seem. CAD is being used at the company in the context of a reorganization designed to shift skill and decisionmaking as much as possible toward the point of origin of the data stream, reducing the autonomy and the need for judgement in designers further down the line. Smith and Jones predict that the average skill level of engineers in the departments at the head of the stream will increase, partly because of a need for training that is more technical as opposed to general, and partly by the elimination of the less skilled employees. Further downstream, engineers will process a much more fully-defined set of data and will operate on computer-transmitted information in a more standardized way. The amount of skill and judgement necessary for this work will be reduced, the CAD/CAM Integration Team predicts, although at the same time the relatively routine input-output jobs will be substantially eliminated.

CAD eliminates entirely the necessity for certain skills. As one engineer said: "If you have a CAD machine I don't know that you need [drafting] knowledge anymore. It is built into the capabilities of the machine."

Two engineers observed that at the company, many jobs now done by engineers could soon be done by technicians. One engineer illustrated this by the experience of his department:

> A lot of the jobs they have engineers in, a technician can do. They have to train the engineer,just like they train the technician. In a lot of cases they are spending a lot of money for that engineer, where the technician with the same amount of training can still perform the job. There are enough checks when you get 200 people in a group that in the end it is going to come out right whether the guy makes a mistake that the engineer wouldn't have or not. I think we are seeing more and more technicians come into the area. I can remember when I first started that 60 or 70 percent of the group was engineers, and it is probably 40 percent now.

Wire Information and Release System (WIRS)

The Wire Information and Release System (WIRS) is representative of the integral role computers play in organizing production at the company. WIRS uses computer technology to cope with the burgeoning complexity and amount of wiring in jet aircraft. As airplanes become more sophisticated, electronic components take over mechanical functions. Moreover, the electronics are increasingly digital which requires more wiring than analog. On a Zeta the end result is 423,000 feet or 80 miles of wires, divided into 747 bundles and 42,000 segments. This is twice the amount of wiring that was utilized on the company's first jetliner, the Alpha. A further complication is that wiring is among the parts of the aircraft most frequently changed, stemming from the proliferation of models and rapid technical advances in electronics.

WIRS was introduced into production in November 1978 after 5 difficult years of planning and experimentation. The system identifies, controls, and accounts for the wire configurations, and also monitors changes and provides status accounting of the operations. Prior to WIRS a partially automated configuration management system was in use. It was a batch system that necessitated handwritten fabrication orders.

Management maintains that the advantages of the new system are substantial in terms of engineering flow time, accuracy of information, and configuration control. Changes and new designs flow more quickly because computer data rather than paper is being transmitted. Overall, WIRS provides a much higher visibility of all wiring operations to management. On the shop floor where the bundles are assembled, the actual assembly process remains the same. The coordination between design and production, however, is substantially improved.

Integrated Data Base Systems Development

The CAD/CAM Integration Task Force is not the only effort underway at the company to smooth the data flow. The integrated data base plan seeks to update and tie together existing engineering and operations systems. Today there is an extraordinary range and diversity of these systems covering all aspects of the company's activity. Three examples of these systems are the Automated Parts List (APL), which automates the production of engineering drawing parts lists; the Master Schedule Update Program (MSUP), which automates the generation and use of master schedule data; and SROA, which is an automated ordering system. Most of the current mainline business systems are 12 to 20 years old. They are costly to maintain because of a lack of documentation and the constant modifications that have taken place over time. In particular, batch serial systems are now considered slow and inefficient. Entire files have to be read to alter even a few records. In addition, because these systems were developed independently, there are wide differences in software, design, and communication protocol. Consequently, consolidation is difficult if not impossible.

The development of an integrated business management system depends on the creation of a common data base. This in turn is aided by standardized communications and terminal networks. The effect of these changes on the organization of the company is significant. The actual effect on the work environment, however, will likely be less dramatic. Essentially, first or second generation computer systems are being upgraded to second or third generation systems. In this case, smoother flow does not necessarily mean occupational restructuring.

IV. NC IN THE PRODUCTION MACHINE SHOP: A MATURE COMPUTERIZED TECHNOLOGY

Numerical control (NC), one of the earliest computerized manufacturing technologies, can be seen today at the company in a relatively mature form. First developed for use in the aerospace industry in the early 1950's and subsequently spread to other industries, NC has been in use at the company for more than a quarter of a century. To understand the long-term effects of the use of this form of computerized technology on the work environment, the research team visited the production machine shop at plant B.[24]

NC is a control system which, when harnessed to a machine tool, can automate many of the control functions previously performed by a human operator. Using computer-coded data, NC controls govern the movements of machine tools as they remove metal to form a finished part. The NC control guides the machine tool through a preprogrammed set of actions, reading instructions from a coded tape. In the case of NC's more recent electronic refinements, computer numerical control and direct numerical control, the instructions are stored in a microcomputer at the machine itself (CNC) or sent directly from a central computer (DNC). With all NC technologies, the decisions about how to produce a part, made by the machinist where conventional machine tools are in use, are made instead by the person who writes the program off which the tool runs. In many situations, it is technically possible for this programming to be done by the machinist, but in almost all cases it is done off the shop floor by an NC parts programmer.

The use of NC in the aircraft industry has brought about substantial changes in the industry's production capability. NC was originally developed, with Air Force support, for use in aerospace applications, and it makes possible the manufacture of a class of complex parts that would be unfeasible with conventional equipment. NC also has a positive effect on productivity in the aircraft industry because of its speed, its inherent repeatability (since parts are made from a recorded tape), the reduced setup time needed, and the possibility of cutting multiple parts simultaneously on a single machine.

NC technology is at the heart of computer-aided manufacturing. At the company, the NC machine is the point at which the data gathered and reworked in the "data stream" are put into use in actual production. NC is a technology integral to the changes now underway, and it will also play a pivotal role in the integration of CAD and CAM. Yet, at the same time, it is not a new technology; unlike many other applications of computer technology, NC has long ago outgrown any shake-down problems that may have existed at the time of its early introduction. What one sees in the plant B production machine shop, then, is a mature example of the use of programmable automation.

Prior to the introduction of NC, the planning department made many of the detailed decisions about manufacturing a part--such as the cutters to be used--and then transmitted instructions to the shop floor in the form of drawings or other documents. Although machinists were supposed to follow these instructions, in practice this was difficult to enforce. NC, however, makes it possible to technologically remove from the shop floor much of the decisionmaking involved in part production, taking away from those at the point of production a substantial amount of discretion and moving it to a different place in the organization. This transformation, begun in the NC shop a quarter-century ago, exemplifies the sort of organizational change sought on a wider scale at the company: a "revolution" which moves skill and decisionmaking to an earlier point in the design and manufacturing process. Many of the most striking effects of NC on the work environment of the machine shop are a result of the organizational restructuring which NC makes possible.

The Machine Shop

The NC machine shop at plant B covers an area of 471,000 square feet, about the size of 18 football fields. Some of the NC machines in the shop are as much as two stories tall -- so large that the operator has an elevator that runs up the side of the machine, since some operations require access from above. The machines are laid out in aisles, and each machine has a number which it is given for identification purposes. All together, there are 110 NC and CNC and 230 conventional machine tools in the shop.

Six hundred and thirty machinists are currently employed at the machine shop. Most are members of the International Association of Machinists. Many of the machinists interviewed for this study had well over a decade of experience running NC machines at the company, although few were journeyman machinists. The pay grade for an NC machinist, depending on the exact classification, is generally 8 or 9 out of a maximum of 12 grades.[25]

The production machine shop is used for both prototype and production machining work. New designs are first machined here as a support to the development process, and new program tapes for parts which have reached the final design stages are tested in the shop as well. For each new airplane model, a stock of parts sufficient to build at least the first five complete airplanes is produced in the production machine shop. Parts for subsequent planes of the same model sometimes are farmed out to subcontractors, except in cases where the company feels that none of its subcontractors around the world are capable of meeting its requirements or where production in-house would be more economical.

As a consequence, the machine shop produces an ever-changing variety of parts, cut to very exacting specifications. Some of the parts machined are extremely valuable, representing an investment in materials and labor that may run into the tens of thousands of dollars, so that a mistake can be very costly While many small parts are made in the shop, others are extremely large, and some machining operations may last as long as several days. Because of the nature of the product and the importance of precision, and because of the value of the parts involved, ensuring-quality production is crucial in the production machine shop.

NC and Changes in the Work Environment

Increased Interdependence in the Machine Shop

Both machinists and supervisors in the NC shop reported that in an NC area they were more closely linked to other departments and groups than was the case in areas with conventional equipment. By making it possible to remove a substantial amount of planning work from the shop floor and moving it to other areas such as programming, NC control systems increase the number of actors involved in the direct production of parts. In the process of bringing in other participants, the autonomy of the machinist is substantially reduced. NC tends to be more capital intensive and productive than the conventional machines it replaces. Consequently, far fewer workers--including programmers and machinists--are needed on NC than on conventional equipment for a given amount of work. Since NC requires more support functions, however, the number of people tied to the operation of a specific machine increases.

This phenomenon was described by a machinist who said he preferred running NC machines to running conventional ones, but did not like the way in which NC increased his dependence on other groups:

> On a conventional machine it's pretty much just between you and the machine. Somebody brings up a tub full of parts and says, "Here it is. Go to it." On the NC machine you've got the programmer, you've got NC tooling, and you've got planning, and if any one part of it breaks down, then the whole thing goes. If something bombs out on the program, they have to connect with tooling to make an alteration on the tooling, and these are separate organizations...and this guy only works day shift so you got'a wait till tomorrow to get ahold of him and it gets quite involved. When everything clicks it's really nice because on the right type of job you get tremendous output and everything looks very impressive. But one thing can easily break down and you've got a problem.

For this machinist, running NC felt like being on the front lines:

> When you're running NC, there's this whole big tail behind you that's a lot bigger than when you're running conventional. There's you and the machine down there, but there's all these guys behind you that aren't as involved or aren't even there if you're running conventional. I kind of have the same feeling I had when I was in the Army. I was drafted, and I was the guy out there. And I had all these guys behind me, way behind--the clerk and supply and intelligence and whatever...it's the same type of idea. For one guy that's actually out there beating the bush, there's 20 or 30 guys back there somewhere supposedly supporting him.

Supervisors also reported increased interdependence with other groups performing related support functions. One NC supervisor said:

> Supervising NC, you have to deal with more support groups. You're more vulnerable to their preferences. There's more negotiation beforehand with people like programming and fixturing.

Decreased Autonomy

One of the fundamental features of NC machinery is that it creates the possibility of separating the act of planning the machining job--that is, the writing of the parts program--from the execution of the machining task. Decisions about the order in which cuts will be made and the exact approach employed are generally made in the production shop by programmers rather than by machinists. This organizational change reduces the autonomy of the machinist very substantially, constraining his or her ability to plan and control the part-cutting process. As a result, the most central aspects of the conventional machinist's skill are removed from the shop floor and transferred to the programming department.

Supervisors are also more constrained in their ability to arrange how and when a job is done than they would be in a conventional shop. When orders come down to the shop, many of the decisions that a supervisor might make based on present workload, available operators, and so forth have already been made. For example, parts programs are written for particular machines and cannot be shifted at will among available machines. One supervisor described NC as "a canned operation", saying, "you're limited in what you can do."

One consequence of the decreased latitude given to NC supervisors is that they reported finding it more difficult to meet production deadlines in an NC area than in an area with conventional machinery.26 In a conventional area, a supervisor might alter the schedule or shift jobs among machines in order to expedite the flow of work. In the NC area, many decisions of this sort have already been made before the job arrives on the floor. In addition, because there are now "more people to coordinate with", as a supervisor said, jobs are subject to the delays described by the machinist above who said that parts are frequently held up because a needed person is unavailable.

Some supervisors in this shop complained that, at times, they no longer received information about the part being machined that previously had been provided automatically. "Now sometimes we don't even have dimensions for drawings", said one NC supervisor. This can make it more difficult to spot and repair problems immediately, and reduces the amount of decisionmaking and discretion which supervisors and machinists can exercise.

Boredom: A Major Complaint of NC Machinists

The removal of most of the planning and decisionmaking activity leaves a void in the NC machinists' job; this leads to problems that tend to interfere with doing alert and exacting work.

NC operators in the machine shop agreed overwhelmingly that boredom was a very serious problem on their job. Most were skilled machinists with years of experience running NC machinery; yet, while vigilance was required, their work largely consisted of routine interventions in a preprogrammed operation.

Boredom was, for these NC machinists, a widespread problem. This is particularly interesting to note because NC is often thought of as the technology that eliminates routine work, freeing the machinist to perform the more skilled work of conceptualizing and managing the machining production process. Aspects of machining work in the NC shop which contribute to the complaints of boredom include:

Little intervention: The coded instructions on the NC tape or in the computerized control have embodied in them much of the planning work formerly done by machinists. While skill is still needed in the machining process, it takes the form of the need for alert supervision of the machine, rather than continuous active intervention on the part of the machinist. A machinist who has run an NC milling machine for 10 years said, "My jobs last 2 or 3 days, sometimes one week. I change cutters, but otherwise I just stand there and watch it." Another machinist with 5 years of NC experience reported that "sometimes you feel like a glorified babysitter."

Long cuts: Some parts take as long as several days to produce. While the part is being machined there is no need to do setup work or other things that contribute variety to machining work. One machinist described what it was like to work on a long job:

> If you've got a long cut, you stay at it. You want to put out a good part, so you don't want to wander off while your machine's running. You might be cutting stainless, you're watching that cutter, you're waiting for that cutter to just, c'mon, get out of there, do something--and you may be in there for 2 days.

Another machinist said:

> For 2 years, we put jobs for those engine mounts on the G & L's. They literally stayed on the machine for 3 days before you took 'em off. You had four sets of cutters, you came in, you put 'em on, you'd go to sleep.

A third machinist said that boredom was less of a problem on smaller machines, which run smaller parts with shorter cutting cycles:

> I found on the little machines now it isn't quite that way [i.e. boring], unless you get on a stainless job or something. On little machines, you're whipping right along. You don't really have time to sit down that much. But on the big machines--and I've been there too--boredom sets in. Especially if your neighbors have walked away from you.

A machinist added:

> I've had more fun since I got off the big machines and went down into my current area. I really enjoy my job now. Whereas before, I was worn out.

Lack of machine variety: Some machinists said that the fact that they were assigned to one machine for years on end contributed to the boredom they experienced. By contrast, apprentices learn to run the full spectrum of machine tools. By the time they complete their course, they are familiar with a wide variety of machines. One machinist observed:

> There is something that I have never understood about the company down there. They have an apprenticeship program. They have 4 years of it, and once that person has made that level, normally, he goes on one machine in one area and that's it and 5 years from now I'm sure that some of the people there have forgotten how to do anything other than run that one lathe, that one CNC mill, or whatever. It's really a shame to see all that talent go down the tubes.

Some machinists said that they would like to rotate among machines; others said that they would prefer not to. All agreed that it takes time to learn the controls of an unfamiliar CNC machine, making it somewhat more difficult to move among machines but also more challenging to do so.

One machinist described the effect that running NC had on him--a description with which most other NC machinists concurred:

> I think what happens is you get lazy. You sit and you run those machines and you get lazy. I can sit all night on the machine and go home and be tired. I've told myself to stop being tired. I'm not tired--I'm just bored.

NC operators reported that the lethargy that developed from long periods of inaction interfered with their ability to do their work most effectively.

> The hardest thing to do is to keep yourself on your toes checking the measurements. Just because the tape says it's good, it's not necessarily so...You get to relying on that tape and what the machine can do, and sometimes the boredom--you know, you'd just as soon put another part on and just sit down again. How many times have you loaded the same machine and come to a cutter change and you've got those fifty pound cutters? And you say, oh my god, I still have to change cutters...

Boredom: A Problem for Production

A machinist in the production shop expressed a widely-held view about running NC machines:

> You don't have to think anymore. You lose touch with what you're actually doing because everything's been told. You've got a set of documents, you've got your tapes, and you've got a set of instructions as to how to set the machine up and run it, and I believe you yourself become a robot because you don't get to use your mind. On a conventional where I'm at now, I still have to calculate things out, I still have to use my mind in how to read a blueprint, how to use my tools, and how to set the machine up...If you don't do it this way it just won't work right, so you have to do it this way. If they would allow the operators to do their own programming, then I believe that the utilization of your mind is an advantage.

This same machinist, however, later went on to say that in fact the effective operation of NC equipment required considerable alertness and skill:

> There are operators out there that just trust the computer, but I think that in order to be a good operator, you have to be able to see several steps ahead of time to know what the computer is going to do. And the CRT [video] screen offers that information if you're watching for it. So you need to read the programs in order for you to know what it's going to do ahead of time. Otherwise you end up seeing things like cutters running into clamps and things like that, because people aren't paying attention.

In contrast to this opinion, some managers argue that once a program is complete, the operator is not supposed to monitor the program by knowing the next block of data.

but rather is expected to be watching only the cutting conditions. The operator's duties, in this view, are to make the necessary adjustments to the feed rate and spindle speed (based on factors such as vibration, noise, and surface finish) to insure the proper cutting action. The machinist is capable of acquiring at the machine tool the skills needed to intervene in this way, and a broader understanding of the machining process is not really necessary.

This view, however, may seriously understate the subtle relationship between an awareness of broad machining principles, i.e., planning the order of operations, selecting the proper cutting tools, and monitoring the actual cut. When a problem does occur while machining a part, for example, the operator may require remedies other than changing spindle speeds and machine feeds -- remedies that stem from a broader understanding of the entire process. Moreover, a machinist can sometimes play a key role in optimizing a program even after it has been run several times, based on an interplay of understanding broad machining principles and close observation of the cutting conditions.

The value of the machinist's input poses a fundamental problem inherent in the partial, but not complete, removal of the machinists' skill, judgment, and attention: the substantial relocation of planning work to a planning department leaves the machinist with a job that continues to require the ability to intervene in an informed way, yet lacks the set of tasks and involvement which are vital to skill development. The work that remains when programming work is done elsewhere demands constant attention of the machinist without offering the opportunity to fully engage in the process of planning and shaping the machining process.

Additional Features of the NC Work Environment

The problems caused by boredom are compounded, NC operators said, by other changes in the work environment that are connected to the use of NC equipment. These problems were considered secondary in importance by the machinists interviewed, yet they reportedly contributed to the strain of working with NC equipment.

Isolation: Operators of the very large NC machines were often bothered by the lack of human contact on the job. A few machinists liked the solitude, but the comments of this operator were typical:

> When I was running the big machines -- a couple of years ago I ran them for a couple of weeks -- it got lonely down there, it really did... Where I'm at now I don't have that problem because they are smaller machines and our machines are close enough so we can still be by our machines and have control over them and shoot the breeze, have a conversation, whatever.

Another NC operator said facetiously:

> I have heard a lot of operators say that on the CRT screens it would be nice if we had a screen below it with cartoons or something across it.

The combination of noise, physical distance, and attentiveness required to run NC machines effectively combine to make machining very isolating work for many NC machinists.

Stress. Two factors in particular contribute to the level of stress involved in running an NC machine. First, the value of the parts, which can run into the tens of thousands of dollars, means that an error resulting in scrapping a part can be a major catastrophe. To make matters even more serious, perhaps as many as half of the NC machine tools are multiple spindle machines, so that often more than one part is cut at a time. As one NC supervisor said, "It's harder to ruin the whole part on conventional machinery. On NC, nine out of ten times you lose the whole thing -- three of them."

The second factor contributing to stress on NC is that the value of machine running time is much greater on NC machines. The machines themselves are far more costly, and because of their speed and their ability to machine multiple parts at one time, the amount of value added per hour is higher on NC equipment. "We're more cost-conscious on NC," said an NC supervisor, "We're more aggressive about keeping the machines running." Keeping the machines running involves both speedy repair when problems arise and also a certain pressure on operators to increase the percentage of running time on each shift, supported by a system of relief operators on the shop floor who fill in for machinists during breaks.

Operators did not talk much about stress in interviews. Presumably, there is a process of natural selection involved here, in that those who do not make an accommodation to the stress present on the job do not continue to work in this environment. One machinist said:

> I used to let a combination of things bother me whereas I don't anymore. Once I'm out that door, I don't bring the problems home anymore.

Noise: The large NC machines can be extremely noisy. Several NC operators talked about the noise and how it affected them.

> The first thing that got to me when I walked in the shop was the size of those NC's. Some of them were as big as houses. And I've take visitors in expecting that type of comment, and the first thing they say to me, after we get out, is, "My God, it's loud in there. I couldn't work under that."

Another added: "you walk in that shop -- you could have twenty lawnmowers running and never hear them." A machinist who now works for the union said about the effect of noise in his life:

> I found myself, after I got out of the shop, noticing a difference in my life. When you come out of there you're kind of zzzzz, you know. The boredom and the noise combination, I think, can really get to you.

The level of noise in an area affects how people working there feel about their work and about each other, machinists reported.

> [In one area] everybody was so jumpy and grouchy. And I could see why. It was so noisy down there. Everybody hated everybody. But you get away from that area and get over to 55 where it's really quiet and it's a whole different atmosphere over there. Everybody's friendly....

Although noise was clearly a serious factor contributing to the general level of stress on the job, there was general agreement that the noise problem had been improving recently, as the machines were switched over from hydraulic to electric drives.

Relationships Between Machinists and Supervisors

In the machine shop, supervisors function as representatives of management on the shop floor. They work to schedule and expedite operations, and it is their responsibility to supervise and evaluate NC machinists. Detailed technical and scheduling problems in a particular area, however, are generally dealt with by area men or leaders. They are selected by supervisors from among the most experienced machinists on the shop floor, and remain hourly workers as well as union members.

Supervisors, by virtue of their position, tend to lose touch with the details of a machinist's daily work, thus making them relatively removed from the detailed daily problems that NC operators face. In addition, supervisors are rotated frequently among areas, preventing them from getting to know any single area very well. Supervisors, however, have the authority to evaluate the performance of operators and to discipline them.

Operators interviewed perceived the area men as performing the truly important functions in the shop. One machinist suggested that the supervisor's job could be eliminated entirely, while another said that a supervisor could easily run two areas instead of one. "The area man is doing 90 percent of [the supervisor's] job," said an operator. Another said, "The area man is in a powerful position in the machine shop because he doesn't change. He stays in his work station on his shift for years." A third machinist added:

> And he's not chasing hot parts around the shop, either, [the way the supervisor does]. He knows what's happening in his area. He could grade the operators more accurately than the supervisor. You'll see a supervisor once every 24 weeks, and he'll write down a little "A" [a performance evaluation] because you walk slowly.

Operators reported that they would have to be in serious trouble to call on a supervisor for assistance. Supervisors were generally regarded as being unhelpful and obstructive, while area men were seen as helpful and knowledgeable.

> The guys really look up to [the area man] and look for him to make the decisions. A lot of times -- 90 percent of the time -- that area man will amaze me because he'll make that decision without checking with the supervisor at all. Usually if he checks with the supervisor it screws everything up.

Effects on NC on Worker-Supervisor Relationships: Tension and conflict between workers and their supervisors is nothing new, nor is it a consequence of the introduction of computerized machine tools. Yet technological change does affect the relationship between machinist and supervisor in the machine shop. Operators tended to regard supervisors as unknowledgeable about the details of the operator's work, and the complexity and variety of CNC controls found in the shop makes it even more difficult for a supervisor to be well-informed enough to give helpful advice when a machinist encounters a problem. One area man interviewed admitted that even he did not know how to use the machine control to edit a program until he was demoted to operator during a wave of layoffs.

NC also offers a particular focus for the conflicts between worker and supervisor. An NC operator, running a part off of a preprogrammed set of instructions, has had much of the control over how the part will be machined removed from the job. One of the things that the operator does control, however, is the rate at which the program is run, which represents an important element of control over the machine. Using the feed rate override dial, a machinist can adjust the machine so that it runs at a given percentage of its programmed rate. A machinist might to this because of some sign detected during the process of cutting metal that suggests the programmed rate is too fast or too slow. The feed rate override can also be turned down simply to prolong the job, and this is what some supervisors regularly suspect operators of doing, according to several machinists.

The feed rate override dial thus becomes a sort of lightning rod for worker-supervisor tensions, which would have to be expressed in some other form in a conventional area. If supervisors interpret the feed rate at which an operator is running as tangible evidence of whether the operator is working diligently or not, then the feed rate becomes a highly political issue and a symbol of a larger conflict that exists.

According to operators, supervisors varied in how much emphasis they put on running the machine at 100 percent of the programmed rate, but everyone had stories to tell about conflicts with supervisors over feed rates. One supervisor said that in this area there was "constant discussion" over feed rates.

Some of the older supervisors have not run NC machines themselves, having learned the machining trade on conventional equipment. A number of operators felt that problems resulted from this lack of experience in actual machine operation. One operator stated:

> There's a lot of jobs you can't run at 100 percent. We had been running a job for quite a while, and we had an area where we could run about 25 percent, and the supervisor comes down there and says, "You ought to be able to run faster than that." Well, we broke cutters before, trying to kick up the feed rate on them... I didn't know him that well. He had just come down from programming into supervision of the floor, so I just asked him, "Where do you want it? And he said, "Well, let's start it at 60 percent and go from there." So I turned it up to 60 percent and I don't think it was ten seconds and the cutters just shattered.

After a few incidents like this, many supervisors back off on pressuring machinists about the feed rate at which they run their parts. Others continue to press the operators, and these supervisors were the particular focus of machinists' complaints about supervision.

Intervention in the Machining Process

In moving skill and decisionmaking higher in the organization, the jobs of NC machinists are set up to minimize their intervention in the machining process. Before the advent of NC, as noted earlier, the planner provided detailed instructions to the machinists as to how to machine a part. The planner, however, had to rely on the machinist to interpret these directives. The NC programmer not only appropriates this planning function but gains the capability of transmitting instructions directly to the machine, without these instructions being mediated by the machinist. In the areas explored by the research team, machinists are explicitly prohibited from editing or programming at the machines, other than for feeds and speeds. except when accompanied by the programmer or under unusual and very carefully circumscribed conditions. Nevertheless, for a variety of reasons discussed below, some of which have to do with expediting and increasing and efficiency of production, editing is sometimes done at the machine by NC operators.

Technically, CNC opens up a host of new possibilities to increase the intervention of the machinist in the programming process. With NC, most changes in the part program had to be done on a computer terminal and tape punch, which were generally located in the programming office. This location and the cumbersome nature of editing tended to reinforce the separation of programming from the shop floor. On a CNC machine, however, the editing capability is built into the machine control. In addition, some controls are designed to facilitate programming and editing at the machine tool. In some areas only briefly visited by the research team -- principally the drills and lathes -- the company maintains that some editing and programming does take place. However, in the milling areas, the core of the shop's activities, it is company practice that there will be no editing or programming on the shop floor.

There are a variety of reasons why the company maintains this position. First, the complexity of the parts themselves, of the final product, and of the production operation mean that parts must be carefully tracked and good records maintained. Management maintains these controls by requiring that changes be made in the programming department rather than on the shop floor. According to Mr. Black, a programming manager:

> With our numbers of programmers and numbers of machine tools and being able to maintain configuration controls, we don't do any editing of the data itself. The only way we change data, to change the tape, is to change the source code to produce the tape and recompute the job.

Second, although most of the parts produced on the shop floor are worth less than $11,000, some are extremely valuable. Management particularly wants to maintain control of the editing of tapes for parts which, if damaged beyond repair, could mean a dollar loss in the five-figure range. One machinist said, "In our area the parts are so big and valuable even the supervisor dosen't want to edit." Third, a programmer maintained that programming by operators was not cost-effective:

> I think that machines with editing capabilities on them are kind of a mistake for a company the magnitude of (this one) because they have a very big investment in computers to do these jobs. We can do most of the correcting and the rework of programs on the computer much quicker than a man can to it downstairs on his machine. The spindle time on the machines has gotten to be a very valuable commodity.

A programming supervisor prohibited editing by operators because he believed that if operators took the initiative in writing programs, it led to delay and wasted effort because operators might not admit their mistakes.

> Some of the fellows will be doing an operation on a tape that we have sent down and they will get a bright idea that, "Hey, maybe if I do this it will work better or it will look better," or something of this type. And they will go in and edit this program right on the machine and consequently they will make a mistake and it scraps a tool or a part. Certain people do not want to admit right way that they were playing and made a mistake and ruined something. It tends to take time away from actually getting a job done because we end up chasing ghosts. Because immediately the blame is put on the tape ... and if the tape was good, the programmer spends a lot of time trying to find something that is not there. We have had this happen at different times, so I have at the present time got a directive in the shop that they are not to edit any tapes at all. If there is a problem they are to call the programmer and he is to go down and evaluate what's wrong and come back and fix it.

Finally, company's desire to maintain more complete control over shop floor activities appears to be a central motivator. Programming for many aircraft parts is a highly complex undertaking, and there are many parts produced in the shop that could not be programmed from start to finish on the shop floor. For other parts, however, the programs could, from a technical point of view, be written or edited on the shop floor, according to machinists interviewed. In some cases, this would be more advantageous because the machinist is closer to the cutting process. These same programs can also be written in the programming department, the course chosen by the company.

In spite of prohibitions on editing, machinists in the NC shop sometimes do edit parts programs. When this occurs, it is generally for one of the following reasons:

The Initiative of the Operator: It does not seem to be the case that, as implied by the programming supervisor quoted above, all shop floor editing happens because of the interest and inspiration of the machinist. However, machinists did express interest in programming and the conviction that, in at least some cases, they could improve the programs written in the programming department. "They write a program four times as long as ours to do the same thing," an operator asserted. Another operator said, "A lot of the programs are being done by the operators or by the lathe men because they feel that they can do a better job programming because they're writing their own on the floor." Still, even for operators who find programming very appealing, there are strong motivations not to take the risks involved in taking programming into one's own hands.

> Programming from start to finish, it's nice. I have done it going through my apprenticeship and it is not as easy as some people seem to think. It's complicated. It is so easy to make a mistake and in our shop -- I'll just speak for our shop -- some of the supervisors, they're all over you. You have just committed the most fatal sin in the world. They write you up and give you a day off because you made a mistake. As long as you're doing good, you are o.k., but when you're not, if you goof that part up, then you have a problem in our shop.

Simplicity of the Programming Task: In some cases, the programming task is so straightforward and elementary that operators are permitted to program their own machines. Machinists from the NC drill area said that, in the words of one operator, "Seventy-five percent of the programs in our area" are written by operators. These programs are written for two-axis point-to-point drilling, and are thus very simple programs whose chief function is to locate the drill head along x and y axes.

Operators are also allowed to edit in other areas under certain very restricted conditions, and even then the editing is confined to feed rate and spindle speed. Control over the feed rate does give the operator significant control over the ultimate output of the machine, since the operator can decide how fast to execute the program. Nonetheless, this type of editing is very different, both in terms of the skills required and in terms of its intrinsic interest and the level of responsibility involved, from editing in order to solve machining problems or from writing a program from scratch.

Scheduling Pressure: When a sudden urgent need for a particular part arises, supervisors may ask area men or operators to edit or even to program, using the machine's CNC panel. Although officially in violation of certain directives, the practice persists because a supervisor may judge the situation important enough to justify this breach of proper procedure. A delayed part might be holding up an entire operation in another part of the production process, with extremely expensive consequences. Furthermore, if a problem arises on the evening or night shift, waiting for programmers to come in for the day shift introduces additional costly delay. In these cases, editing or even programming at the machine may be far more efficient than sending the program back to the programming department, as official procedure dictates. A machinist described how an operator may be asked to edit.

> If we have tape that is still in a tape tryout and they come down and say, "We need these parts. Let's make this lot." Or, "Let's make this part that takes manual operations on an NC machine to do it," we do it. We will edit the program to make that part. Normally it is with the supervisor or area man's approval. It is not done strictly on the operator level. The supervisor will come down himself and say, "Hey, this is what I need, will you please take care of it?" The supervisors know in an area who is capable and who is not capable of doing that. So they don't walk up and just ask any particular operator to do it. They will see that job gets on a machine where the operator is capable.

Another machinist reported:

> The editing capability is there, but the degree of programming that occurs depends on whether the job that they want done is hot, and whether they're willing to take the risk of getting in trouble for allowing the hourly employees to be programming.

These editing arrangements do not have official sanction, since they are initiated only at the supervisory level; but if an operator edits under these circumstances, the consequences of an error do not fall entirely on the operator, since he or she was responding to a request from a supervisor. Machinists agreed that the disciplinary procedure had never been invoked against an operator who edited with a supervisor's permission, although some said that there were ways of punishing operators for errors, short of the standard disciplinary procedure.

Some machinists felt that they were being given double messages about editing. On the one hand, editing was explicitly forbidden by certain directives. On the other, some machinists were being trained on the job in editing techniques and supervisors were dropping hints that might be interpreted as encouraging operators to edit. One operator said:

> They have a guy right now who came off another shift and he is teaching nothing but editing. To eight different operators at the same time. He was brought in to instruct editing in -- well, I'll just put it to you the same way the manager put it to me. "I'm bringing him on to teach how to edit, in tape tryout conditions only. But if these people want to take it any further themselves, I am not exactly going to discourage it."

This ambiguity has additional significance in a unionized shop. Machinists' reluctance to perform tasks that are officially assigned to another group is partly motivated by concern for the job security of programmers and partly by their reluctance to perform additional work without having those duties recognized in their job description and in their paycheck. A machinist who had been an NC operator for 14 years vehemently expressed his views on how the shop was run with respect to editing policy:

> Supposedly on the new machinery they have bought they have the capabilities of a fantastic computer. You can make over a program, edit a program, you can just do some great things to it. Now they bring in a person and they say, o.k., we are going to teach these guys how to edit these machines. Yet they don't want them to do it. They do, but they don't. "If they want to do it, it is up to them, but we are not telling them to do it." We've got this little cat and mouse game going here. Instead of saying, "Okay, we are going to create a job where we can use this thing to its maximum capacity and we are going to create a title for these people and we are going to teach them everything we can"--they won't do it! They just won't do it!

Relationships Between Machinists and Programmers

The use of NC at the company causes the functions of a conventional machinist to be split in two: the programmer does much of the planning and the NC machinist executes the machining of the part. Because of the overlap of responsibilities and conflicting ideas about how operations should be carried out, there is frequently friction between the two groups.

The company places a premium on a machining background for programmers. About 70 percent of the programming department are former machinists, although the programming manager himself has an engineering rather than a shop background. A machinist compared programmers with shop experience to those who are recruited from other areas.

> Some of the NC programmers came from the floor, where they actually used to run the machines, so they understand the capabilities of the machines and what tools are supposed to do what, and what kind of feed rates and what kind of spindle speeds and things like that are reasonable. And those are the ones that usually have the respect of the hourly employees. All the progarmmers have their names on the tape, so you know the guys, and whether they came off the floor or they're straight out of college. I don't see how they can be proficient unless they've actually had some shop floor experience. Generally you can tell if the tape came off somebody that's been on the floor, because if it hasn't, they do some of the weirdest things on the tape. They don't seem to realize that the machine is capable of moving in two directions in one block of information, or things like that.

Machinists interviewed felt that some programmers did not want any serious exchange with machinists about how programs might be improved. These machinists complained that, in some cases, programmers who were former machinists acted as if they were better qualified to determine operating methods that the worker on the machine tool. The machinists argued that programmers very quickly lost touch with machining practice because the day-to-day feedback was not there. In other instances, machinists felt that some programmers without a machining background were reluctant to admit any errors, lest they lose face in front of the operator. A machinist described the conflicts between programming and the operators:

> It just seemed like two completely different companies involved here. They didn't want to be told the exact thing you wanted done. Because they'd say, "You're not a programmer. How do you know the best way to change it?"

The machinists were sensitive to expressions of arrogance on the part of programmers; when programmers seemed to discount the opinions and advice of machinists, communication could break down, with serious consequences for the effective running of the shop. Mr. Black described his view of the relations between programming and the shop floor.

> A machinist, if he wants to, can make the best part program produce scrap parts, and you can't prove what he did. And we find this. Unfortunately, it's a product of people and personalities. When I was a supervisor in the NC areas, one of the things I always told the part programmers, don't get the shop people and personalities. When I was a supervisor in the NC areas, one of the things I always told the part programmers, don't get the shop people down on you. If you make an enemy of those shop people, you will never be able to produce a good part program. And that's 100 percent true. They won't like anything you send down there if they don't like you... What we try to do is get our programmer to take his tape, take his information, and sit right with the operator, and if they jointly -- so both of them feel like they're contributing -- go through a tape tryout, the programmer listens to the operator's input as to suggested feeds and speed changes and so forth. If he intelligently incorporates those changes, and the shop cooperates, it's a real good relationship, and the operator's input is extremely important. If the part programmer goes down there with an "I'm the boss" attitude and "you just push the button and stand back," then the tape tryout goes on and on and never really gets accomplished.

The development and implementation of CNC at the company has made it possible in principle for both editing and programming to be done on the shop floor. This fact, combined with the considerable redundancy in skills between machining and programming, made machinists very sensitive to the fact that people in each occupation could pose a threat to the job security of those in the other. Especially in a unionized environment, where members are very aware of the important role that occupational boundaries play in protecting the jobs of people in each occupational group, machinists repeatedly expressed concern about their potential to put parts programmers out of a job. In interviews, it was sometimes difficult to determine the level of interest machinists had in doing programming work as part of their jobs, because operators were so insistant that they would not want to do anything to threaten the jobs of programmers. As a machinist asserted, "They've given me a machine that allows me to put programming out of a job. It's not right!" Another said that even when he was editing because his supervisor told him to do so, he felt uncomfortable: "I feel guilty every time I do it. I really do. You've got that thought all the time going for you: I'm taking somebody's job away."

One machinist reported having seen programmers respond to the potential threat which CNC controls -- and thus editing capability -- represent on the shop floor.

> The programming group of course is getting a little nervous about their equipment being on the shop floor, and of course their union is fighting to protect their position and trying to keep the work in the office. Recently they assigned a programmer on the shop floor to study the machine language in the lathe area, and now they're starting in the drill area. They have never before recognized the machine language rather than the computer language, so that they can make repairs if the operator's not there.

Training: A Major Concern of NC Machinists

Some of the strongest opinions expressed by machinists were on the subject of training. The issue repeatedly arose unprompted during interviews, and the unanimous opinion was that there was far too little training for NC operators. Most of their learning, operators said, took place informally on the job. While there were off-hours classes, some said, these did not adequately prepare them to run a complex machine in the most effective way. On-the-job training happened either by personal arrangement between operators or was very cursory and, operators felt, inadequate.

> I have to teach all three of these guys to run my machine and vice versa. Now how can I teach them when I don't know? If I haven't come upon something that my machine can do, then I don't know about it. As big as (this company) is, they should be able to afford sending me to a class to learn that machine and what it can do. They gave me an operator's manual. It doesn't show everything, and over a six-month period it's lost and gone. Our shop won't have an instructor whose job it is to know the machine inside and out and who can teach me how to run that machine. I have to learn it myself. They put a new machine in, I learn it, the first shift learns it from the guy who installs the machine, then he teaches the next shift and that is how we learn how to run it.

"You get the impression," said a tool-and-die maker who had been running NC machines for 5 years, "that management thinks [running NC] is a lot easier than it is." Several machinists observed that in the past 10 years they had had three different CNC control units on their machines, and that each was more complex and offered more to learn about than the last. The primary concern of the machinists who complained about the lack of training was that they believed that they and their machines could be far more efficient and productive if they knew more about what the machine could do. "A lot of the problem is a lot of these people are guessing that this is the total capability of the machine," said a lathe operator. Another machinist offered an analogy from aviation:

> We've got a real problem here. All this sophisticated machinery is being purchased by these managers who go out and find the state of the art and then we have 1983 machinery and 1947 management, and the problem is that until our management's thoughts catch up with their purchasing power we are going to be in this position. It's like having a DC-3 pilot and walking him over to a 747 and saying, "Now look, guy, it's an airplane, too--use it to the fullest extent it was made for." That's what we're talking about. "And if you don't know how to fly it then check with the guy in the right seat because he has probably been in it before and he will show you how the ropes work."

Overseeing the Shop Floor: Electronic Monitoring and Paging System

In one area of the NC machine shop, an electronic monitoring and paging system has been in place since 1975. The purpose of the system is twofold: 1) to expedite shop floor operations, especially transactions between NC operators and their support groups, thus increasing the amount of time spent actually cutting metal; and 2) to monitor shop floor operations, giving information to management about activities in the area where the system is in effect. An examination of the system highlights two key issues; first, that computerized monitoring and scheduling systems provide management with significantly increased amounts of information about shop operations; second, that the data collected require careful interpretation, since their meaning and value are not self evident and are strongly influenced by the context within which the information is obtained.

The system has two major functions. First, it serves as a signal system, allowing machinists to call for an area man, relief operator, kitter (who brings tools), or other support group member. Each operator has a set of dials at the machine which are used to enter a prearranged code. The code designating the person being called is then displayed, along with the machine number of the operator who placed the call, on a lighted board which hangs high over the shop floor. This allows the area man, for example, to know where he is needed at any given time without forcing the operator to leave a machine unattended in order to seek an area man.

The monitoring and paging system also has a second function--it monitors production at the 66 NC machines which are presently wired into the system. An automatic system designates the machine as being in one of four states: running, running at less than 80 percent of the programmed rate, down, or temporarily halted for part handling. A machine is assigned to one of these categories based on information collected automatically from the machine control. The operator may also add a limited amount of information by using the dials at the machine; for example, "operator away from the machine" may be substituted for "part handling."

The computer which stores and transmits the programs for the machines run by direct numerical control (DNC) is housed in a control room above the shop floor, with a view of the surrounding machines. The control room also has a light panel, with a cell for each machine wired into the monitoring and paging system. By looking at the light board, a supervisor can tell not only whether or not a particular machine is running, but also whether the machine is being run at at least 80 percent of its programmed rate. If an operator has put in a call for an area man, kitter, or other support person, that too will be displayed, along with the elapsed time since the machine entered its current state (e.g., part handling). This information is also available on a nearby CRT, and a printer is available to print out information and tabulations of data collected in the system.

Supervisors obtain daily reports from the system, and weekly and monthly tabulations are made in chart form. Generally the data are displayed broken down by area but not by individual machine, although this information is available on request. Charts are reviewed at monthly meetings with supervisors, and both the supervisor of the system and two NC supervisors interviewed stressed that generally the information from the system is used to compare long-term trends.

A new system will soon be replacing the monitoring and paging system in this area of the shop. It will be wired to all the machines in the area, not just some, and will collect more information than the present system. When the research team visited the shop, electronic scanners with which operators would enter information, the first phase of the system, were just being installed.

Increased Production

One of the purposes of the electronic monitoring and paging system is to increase the percentage of actual chip-cutting time on each machine. As the value of the machinery on the shop floor increases, the cost of idle time increases as well. The system allows operators to anticipate their needs--for fresh cutting tools, for example--and to request what they need without having to leave the machine. Instead of consuming time looking for an area man, the operator can simply put in a call and expect an area man within the next 5 to 10 minutes.

At the time the system was installed, a complementary organizational change took place. The company instituted a system of relief operators, who were available to fill in for machinists who needed to leave their machines for any reason. Before this change took place, an operator would have to leave the machine idle; with a relief operator available, the operator could leave and the machine could continue running.

This aspect of the system--its ability to expedite operations, including the addition of a relief operator--has been enthusiastically received by machinists and area men:

> It helps the operator. I don't think management's ever been against the guys not only just going to the head or something, but getting away from their machine...You feel good about it, too, because your machine's still running.

Another operator said that the system made things more organized:

> It's nice because before that it was a problem. It was people wandering around looking for other people that couldn't be found, that were wandering around themselves.

An area man liked the system because it meant that he could work steadily on one thing, glancing occasionally at the board to see whether he was wanted somewhere else:

> With the system there you can do other things in the building and still know what's going on in your area. As an area man, I can go down to the end of the building, be working on something, and know that my area's running o.k.

Increased Visibility

The system makes available to management substantially more information about shop floor operations than was available before. This information is used to spot problem areas, with an eye to changing shop operations and policy where necessary. One NC supervisor described a campaign he had instituted to shape up his area because of consistently "bad charts". "That's one of the advantages of [the system]," he said, "increased visibility."

While data on a chart may have the ring of hard truth about them, the fact is that the data do not speak for themselves. The information gathered from the electronic system, like all data gathered from a production situation, requires interpretation and cannot simply be taken at face value. A machinist told a story which illustrates how information from the system may be misinterpreted if the work process it is monitoring is not fully understood.

> A guy had a job down there, it takes 20 minutes to load a part and 2 minutes to run, because he had all these indicators to set up to get the part going. Well, the next day, here comes his supervisor down there and says, "Lookee here, all this setup time you've got, and look at this little bit of run time. What's your problem?" He just presented it to him like that. Well, the operator was gonna kill the guy, because he said, "I probably never worked harder in the last 10 years as I did last night."

Operators suggested that this sort of behavior on the part of supervisors was unusual, and that most supervisors were sensitive to the fact that variations in the numbers collected were a function of the sort of work being done, as well as the amount of effort an operator was putting forth. The usefulness of raw data alone is limited if a supervisor is trying to check the performance of a particular operator; but because many machining jobs in the production shop have long running times, it is possible to compare the performance of operators who run the same parts on different shifts. If a supervisor sees substantial difference between two operators who are machining the same part on different shifts, "that kind of tells the story," said one supervisor.

Yet another example of the importance of the context to a proper interpretation of the information collected by the system comes from the system itself. When the system supervisor was showing the researchers around the shop, he noticed as he demonstrated the system that several minutes elapsed between the time that a call for an area man was sent to the light panel and the time that the call actually appeared. The sluggishness of the system, he said, distorted the statistics that the shop keeps on the response time of area men, relief operators, and so forth to their calls. A supervisor who did not know that the system itself was responding slowly might attribute the slow response time to those who were being paged by the system. In all these cases, the data provided by the system do not speak for themselves; they must be used with a sensitivity to the way in which the context--the actual conditions on the shop floor--affects the data.

Monitoring

When the monitoring and paging system was first introduced, operators were apprehensive about its monitoring capabilities. One operator said, "It doesn't bother me that much. It bothered me more when they first put it in. It really bothered me. I was upset. It's like having a big television camera looking over my shoulder." Today the system seems to be more widely accepted, even by operators who continue to dislike its monitoring capabilities. One of the reasons for this acceptance is that the system has been in place for several years, and certain limits on its use by management are fairly well established. The company has an agreement with the union that information from the system will not be used to discipline employees, although operators said that individual supervisors could exercise various sorts of informal discipline if they chose to. All operators agreed that they knew of no cases in which the system figured in a formal disciplinary hearing.

A second reason for the acceptance of the monitoring system is that it was introduced as a package with the paging system, which has wide and enthusiastic support among operators. Because the system came as a single system with two functions when it was introduced -- a monitoring function and a paging function -- it seems to have appeared as an all-or-nothing proposition to operators and area men. Most of the machinists interviewed felt that on balance it was a good system, but there was evidence that suspicions about the system's use still exist:

> I've had this happen in my area with a lot of guys. They would come get you rather than use a number because they would think well, they've had to call the area man six times last night, you must be dumb. So they wouldn't use it, because they would think it would be held against them because they had to have the area man so many times.

Operators reported that some supervisors used the system to closely monitor the operators in their area, particularly watching the light in the control room that indicates that a machine is being run at less than 80 percent of its programmed rate.

> We used to go to meetings and they would say, "It is not to spy on you guys, but to find out what you are running." But we have always thought that with certain supervisors, that is what they are going to use it for. It used to be such a joke, watching them run upstairs, come back down and head for these certain machines. You knew right away. I could see them because I am up in the air and I would just watch them head for these different machines and I knew who wasn't running 100 percent out there.

Because of this use of the system, it has been given the shop floor nickname "the spy in the sky."

Operators have found ways to use the system to retaliate for isolated actions which they perceive as unfair. A machinist told of one such incident.

> We have one supervisor on third shift down there who likes to put a 73 on the board for a relief operator on a machine that nobody's running. He wants to see the reaction time of the relief operator. And I've had the relief operator say this a couple of times to me, and I'd say, "O.K., we'll fix him up." So we'd put the relief operator's number in there several times on machines, all of them down my aisle, only 10 feet away from each other, and we'd let the numbers come up on the board, and a couple minutes later we'd take them out, thus showing quick reaction time. And then he leaves that relief operator alone for a while.

Operators also found ways to alter the information going to the light panel upstairs; for example, their machine might be running at less than 80 percent of programmed rate, yet the light in the control room would be out, indicating that the machine was running at close to full speed.

In this way, the information going into the system becomes a social product, rather than simply a neutral indicator of objective conditions on the shop floor. This does not mean that the data gathered by the system are of no value; it does mean that to fully understand their meaning, detailed knowledge of the complexities of both the technical and the social dimension of the shop floor is necessary. With the system, management has gained substantial new insight into operations on the shop floor, including insight into the actions of individual operators; yet, this information must be seen in its context to be interpreted correctly.

Programming

Programming provides the instructions that guide the machine tool and, as such, is a pivotal function in an NC operation. Computer technology is used to transfer the locus of decisionmaking off the shop floor and into the programming office. With the introduction of an integrated data flow, however, many of these decisions can be driven even further upstream or automated entirely, illustrating the dynamic and far-reaching character of computerization.

Since the early 1950's, the company has utilized a very powerful part programming language called APT (Automatic Programmed Tool). Today 90 to 95 percent of part programs that are written use APT. An NC language such as APT is a vehicle for a human programmer to communicate the necessary information for machining a part to the computer, which in turn produces a machine-readable program. APT looks like a stylized form of English, a blend of words and symbols that are organized according to strict rules and conventions. All instructions must be written down, statement by statement, in a totally error-free format. Even correct instructions in the wrong order will not work. These instructions cover every machine motion, the feed rates and spindle speeds, and auxiliary functions such as tooling. APT is an exceptionally powerful language in its ability to describe complex three-dimensional shapes. It is also cumbersome to use and error-prone because of its complexity. Twenty tool-motion commands, for example, might be necessary to produce a geometric surface. The process of weeding out errors--checking the format, evaluating the mathematics, and verifying the cutter motion--can require many iterations.

The company is now also using Interactive Computer Graphics (ICG), introduced in the mid-1970's, for about 5 to 10 percent of its programming work. If the part is designed using CAD, the geometry can be made available directly to the part programmer, eliminating the error-prone intermediate step of engineering producing a drawing and the programmer having to interpret it. In some cases, however, the geometry is manually entered into the graphics terminal by the programmer or digitized from a drawing. Once the geometry is there, the programmer can plot tool paths interactively, with the advantage of an immediate visual display of the results. After the entire path is generated, the programmer can verify the cutting tool motion, insuring that the geometry-is accurate, the order of operations is optimal, and no errors have been made, such as machining a clamp. The CRT can display different views of the part and tool paths, including a 3D representation of the cutting process. Other parameters such as feed-rate and spindle speed can then be entered.

A long-range goal is to replicate in other, more complex applications the automatic programming features found on the graphics automated template system (GATS). GATS will automatically generate a cutter path from the part geometry once certain parameters are entered. It is limited, however, to simple two-dimensional work. The templates it produces are flat metal parts that guide a cutter or a drill in an assembly operation. Using conventional methods a highly skilled template maker would scribe the raw metal stock and then perform the necessary drilling and cutting operations. GATS replaces these manual methods with interactive graphics and NC. A programmer can design a template on the CRT screen using a light pencil and a menu, or the design data can be entered into the computer by "digitizing" a drawing. Digitizing involves tracing the relevant dimensions with a hand-held pendant. Once the part geometry is in the system, special software automatically produces an NC tape. The tape is then transferred to an NC machine that produces the template.

When the template is designed on GATS, all intermediate steps are eliminated between the point of design and the manufacture of the part. The programming is done by former template makers. Once the data are entered into the computer, considerably less skill and fewer numbers are required to produce templates.

There was universal agreement among the programmers and managers interviewed that computer graphics was much faster than APT for two-axis work such as lathes or drills. However, according to the programming manager, graphics is not faster than APT on more complex work, but fewer mistakes result because the programmer can instantly see the tool path plotted on the screen. Fewer programming errors make possible a reduction in tape tryout time (TTO), a considerable savings since very expensive machines are considered nonproductive while a new program is being tested.

There was also agreement that less skill is required to program simpler parts with graphics. One programming supervisor commented, "The computervision system or that type of system will probably eventually replace the less-skilled programming types at APT." However, some programmers maintained that on more complex work increased planning was needed on graphics compared to APT. Overall, Black projects that "as we move toward automation [computer graphics] there will be less skill required." He emphasizes, however, that more skill will be required in developing the routines that allow the system to generate the programs.

Smith believes that NC part programming is an intermediate function; consequently, he predicts that a controlled data flow will be able to eliminate a good part of the programmer's job and that this is the direction in which automation should be developed. A programming supervisor disagreed.

> I have been in this business since '67 and there was actually talk prior to that of eliminating this requirement for programmers. That we would be able to set up a screen with a light pen and do everything on the screen. That was nearly 20 years ago and we have not, as of yet, done it. I keep seeing the need for more programming personnel and more skilled people with more ability in programming. I think the need for the less skilled programmer is diminishing.

In fact, over time there has been a steady erosion of the numbers of programmers needed per machine. At best, however, this ratio is only a rough guideline. Programming needs for the same machine can vary widely as a result of part complexity or the number of new orders that come into the shop. According to the programming manager, 1968 and 1980 are comparable years in terms of product activity. If anything, the parts were more complex in 1980. In 1968, there were 1.33 programmers per machine tool, while in 1980 the ratio had declined to .96. By 1985, it could be 0.5 programmers per machine. An important element in this reduction is the increasing use of computer graphics. By

1990, the programming manager feels that 75 percent of the programming work could be done on graphics and that tape tryout could be cut by 75 percent. The number of programmers, however, would not decline as rapidly as the ratios because of the increased numbers of NC machines.

Since programmers are in an intermediate position they must relate both to the shop floor and engineering. Some programmers complained about their relations with the shop floor, mirroring some of the complaints machinists had about programming. One programmer complained:

> The shop can frustrate you with petty things. "We want this and that." Sometimes they don't tell you until the second or third time you run the tape. There is also a lack of education in feeds and speeds and an ambiguity between operators.

Another programmer commented:

> There is some competitiveness between operators and programmers. The programmer is taking away an important part of the machinist's job, part configuration, and a lot of machinists want to show that they know more than the programmer.

A programming supervisor concurred. "Some of the machine operators tend to have a little chip on their shoulder anyway," a situation that is exacerbated when the programmer does not have a machining background.

Relations can also become strained with engineering. The same supervisor commented:

> Usually they are pretty good. I think that sometimes there is a certain amount of resentment going from programming back to engineering, and that you have to be very careful about approaching engineering if you find an error or think that we have found a possible error or something. Or even when we ask them to make a re-evaluation design to make the manufacture of a particular part more economical or feasible...they don't act like they are very happy to find someone else finding something that they may have errored on.

NC Quality Control Inspection

An interview with four NC quality control inspectors suggested that in this small area, which in the machine shop employs 38 inspectors, some of the overall themes and problems of computerized automation were present. While NC inspection is very different from NC machining or the use of CAD equipment, some of the same overall themes were exemplified in this area as in the NC machine shop and engineering design.

NC inspectors take parts that have been machined in the NC machine shop and inspect them for defects and to determine whether they fall within specifications. They compare the drawing of the part to the measurements of the part itself, and then decide whether or not the part is acceptable. NC inspectors use computerized inspection equipment which runs off of programs written for the purpose of inspecting a particular part. In this way, many tasks previously performed by inspectors using manual equipment are automated.

Attitudes of Inspectors Toward the Use of NC

NC inspectors expressed interest in NC as a technology, and were impressed with its speed and its capacity for automating manual functions. An inspector with 29 years of shop experience, two of which have been as an NC inspector, said: "It fascinates me, the way [the machine] can make child's play out of a complex calculation." A young inspector said that he preferred NC to manual inspection methods because NC eliminated repetitious work. "You can just go on and on. You never have to do the same thing over again. There is no limit on it, to what you can do with it. It is just a matter of what you want to learn and what you want to go after." On the other hand, an inspector who had spent 25 years in the shop found himself bored during the inspection process.

> I like to run the computer and figure out the programs and what needs to be done, but I am bored once you take over the machine and start checking a part. And if it is a long and involved process of checking the thing--if it is a four- to five-hour job just checking points on a part to see if it is any good--I get bored with it. Mechanically, if you are just checking, it is the same thing. Making your setups and establishing the starting point is the interesting part for me, but I get bored checking the parts if it is just a matter of drawing lines and then making a new set and drawing more lines. So I get bored with the actual inspection part of each job, but I like the challenge of the problems you run into with layout.

For this inspector, then, the part of the job that appealed to him was the part in which he was making independent decisions and solving problems of strategy and technique. NC inspectors, unlike NC machinists, write most of their own programs; thus, they have the opportunity to engage in this sort of planning and then see the results of their effort.

Of the four inspectors interviewed, one, who had 8 years of shop experience, was by far the youngest of the group. The other three had an average of 28 years of shop experience between them. These three older inspectors expressed serious concern about the possible effects of NC inspection equipment on their craft, and particularly on the ability of the inspector to grasp the underlying process behind the production of parts as well as the use of those parts in a finished airplane. One inspector believed that his experience with manual equipment and his knowledge of machining made him far more valuable than someone who simply knew how to check parts in a rote way.

> I think where my background--I mean the basic skills--comes in handy in my job is that if they are having problems on the machine I am able to recall some of the things that I gained my knowledge from years ago of "what are the problems." You can identify it as cutter problems, clamping problems, a lot of problems that are basic, where if a person didn't have a background you wouldn't be able to pick some of these things out.

Another inspector, who had been doing shop work since the early 1950's, emphasized the importance of judgement in the inspection process--judgement that he believed was only acquired through extensive first-hand experience.

> I think you become a more valuable person if you know this background. To say that black is black and white is white is one thing, but what if you have to mix them and come up with a grey? You have a grey area and you're going to have to figure out some of this stuff and sort it out. Everything that we put out on paper isn't all 100 percent good. Sometimes it's out of tolerance, but we have to use our background and knowledge to figure "can we buy this?" "Is it going to hurt it?"

He went on to say that, in his view, this experience and ability had to be embodied in the person who was doing the actual inspection, rather than someone elsewhere in the organization.

Programming for NC Inspection

The official procedure for programming and operating NC quality control equipment is like that in NC machining: there is an NC quality control programming department. where 25 programmers are employed to write programs for the NC inspection machines. NC inspectors are then supposed to run these programs on their inspection machines. All of the inspectors interviewed felt strongly that to separate the writing of the inspection programs and the actual inspection operation was highly inefficient. As one inspector described the situation:

> There is us and there's the NCQC programmers. They will write up programs and they will send them down for us to run on our machines whenever we get a certain part number in. Then we are supposed to check [the programs] out, see if they are any good, and write down the problems and send them back up there. It is really a waste of time, and the programs really aren't any good. So we have just been making up our own right at the machines because it is a lot faster and you do the best job and you can check it the most accurately in the shortest amount of time. We just make them up as we check the parts, or with some parts you don't need to make them up. We just tell the computer what we want it to do and check the part.

The inspectors felt that the programmers "upstairs" did not understand what was really involved in NC inspection and that they were not committed to making the inspection operation as fast and efficient as it could be. As a second inpector put it,

> Sometimes they will have them backwards, reversed, upside-down, whatever, so we sit there and we try to figure out how to reprogram the thing to get it to where we can work with it easy. Then you go from there. Now it has become a joke. I think that they are taking the programs too fast and they don't know our problems. They really don't care. And some of them make it a fun thing. I had nine like parts, and they had nine ways of starting out. Instead of starting at the top, they will start at the side on one plate, the other side, or the bottom, and it looks like they are running little patterns and playing. We have to straighten that out.

The NC inspectors viewed the NC inspection programmers as dead weight in the system, impeding their ability to do their job in the most effective and timely way.

> We felt that the quality control programming people were learning from us in the shop. That is when they first became involved in it, and I really believe that is how they learned their trade. Then they started mandating that we go through them to get some results, and production came to a halt. We finally had to go on our own, develop our own programs, and get the job done. After about 2 years of this they are eventually catching up to some degree.

Although the NC inspectors, by and large, were doing their own programming, they still needed certain types of documentation that they could only get access to through the programming department. The inspectors realized that by taking programming into their own hands they threatened the jobs of the inspection programmers, and that the programmers had a stake in continuing to control the data and documents routed through them, since these were among their sources of legitimacy.

A union official present at the interview pointed out that, from the point of view of quality control it was very important that the company have carefully established procedures to track parts through the shop and to ensure that parts were being produced according to specifications at every point. The complexity of the product and the crucial importance of safety considerations, he said, made it critical that each step in the production and inspection process be documented.

> I would say that there is some credibility to the check-and-balance system. I don't think that you can say that it is totally an excuse. There could be a system developed on the shop floor that would do the same thing. They could have one person to handle all of that, run the computer and check all the parts' numbers in APT and the latest drawings and revisions that come down. You'd just go in and check it over and see if it's got it and if not, add it on. That would take care of the problem right there.

Finally, the inspectors felt that their communications problems were not limited simply to their relationship with the programming department, but extended to other areas in the organization. These inspectors, who were seeing the effects of relatively limited efforts to move skill and decisionmaking elsewhere in the organization, believed that they were having problems because higher-ups did not understand the nature of the inspectors' task and the constraints of the production process. The NC inspectors, like NC machinists, have the task of uniting data from the data stream with a physical production process. In so doing, they encounter incongruities and errors which may have been generated further "upstream".

> There is a horrible lack of communication between the floor and upstairs, and that is the same anywhere. But there is a fixation with the fact that because an NC machine prints out to the fourth place that it is accurate to the fourth place. This is a fallacy...Engineering--sometimes I don't think that they realize how much a thousandth of an inch is and so when they start dividing that by ten, then asking for tenths of a thousandth, the machines will read out within tenths of a thousandth, but just due to temperature changes in the shop that has got to vary a little bit.

Overall, inspectors believed that they could do their jobs far more effectively if officially given somewhat more latitude and responsibility, instead of having to do programming on an unofficial basis, impeded, as they felt, by established procedures.

V. COLLECTIVE BARGAINING

Two major unions represent workers at the corporation's facilities in the area visited by the research team. The International Association of Machinists (IAM) has 24,450 members, and a professional association of engineers, scientists, and technicians has about 19,300 members. The professional association, the largest of its kind in the United States, has 11,400 people in its engineering unit and 7,900 in its technical unit. While the IAM represents over 90 percent of the eligible workers, the professional association represents about 60 percent of its potential bargaining unit.

In addition to issues such as cost-of-living allowance (COLA), benefit programs, entry rates, and subcontracting, technological change emerged as a major collective bargaining issue for the first time in the 1983 negotiations. The IAM has introduced a preliminary document called "The Technology Bill of Rights" that seeks a major role for the union in the way decisions are made relating to the development and use of new technologies. In addition, the IAM adopted a nine-point package of "model language" in

May 1983 that specifically targets protection against displacement, which the union feels could be large as a result of the introduction of new technology. Technological change was also a major issue for the first time with the professional association. The association stressed the updating of skills and training related to displacement.

VII. CONCLUSION

The company, a West Coast manufacturer of commercial aircraft, is using programmable automation to transform its operations. The result is far-reaching change in the use and transmission of information, as well as in the organization of work, that has profound implications for the work environment. While much of the reorganization of white collar "hands-off" work is still in the planning stages, pilot projects are already underway. In the NC area of the production machine shop, computer-control principles were introduced more than a quarter-century ago, making it possible to observe the effects of a mature application of programmable automation in a manufacturing context. This final section will discuss the company's use of computers in the overall design process, and then focus on the effects of computerized automation in the production machine shop.

To increase its effectiveness as a medium-batch manufacturer, the company has installed at various times a wide variety of computerized systems covering a broad range of applications. Until now, however, there has been little coordination among groups with respect to the use of computers, with the result that there is little compatibility between systems. Because many parts of the organization use similar information for their operations, a key objective of the company is to lay the groundwork for the use of common data by all operations. The most important current effort at meeting this goal is being led by the CAD/CAM Integration Task Force.

In evaluating current procedures, identifying areas that need improvement, and selecting those aspects of current practice that might become models for other parts of the company, the CAD/CAM Integration Team has gone beyond the automation of presently-used methods of storing and processing information. Instead, it is attempting a re-evaluation and rationalization of the entire organization, pursuing change so far-reaching that one of the co-directors of the task force refers to it as a "revolution."

This reorganization of the company, built around the use of CAD to establish a "stream" of shared data, is aimed at moving the decisionmaking involved in design and production to as early a stage in the design and production process as possible, which often means, in effect, moving it higher in the organization. At the point of origin of the data stream, interdisciplinary teams of highly skilled engineers will work to define the basic design and production parameters of a new airplane model. The data generated by this group will then be launched into the data stream, for use by the other groups that must act on the information. Because more of the planning and definition of the aircraft will have taken place earlier in the process--or "upstream"--the subsequent work on the data may require less skill and allow less latitude for engineers and others--such as production workers--who act on the transmitted information. At the same time, the establishment of computer links between groups will eliminate entirely those jobs whose primary purpose is translating data produced by one group for use by another.

This organizational change, precipitated by the company's interest in using programmable automation more effectively, has significant implications for the work environment at the company:

-- The jobs of the engineers at the head of the data stream will become broader and more challenging. The work will require increased technical knowledge of all aspects of the design and production process, as well as the ability to collaborate with other engineers to produce well-defined data for transmission to other parts of the organization.

-- For engineers at later points in the design process, there will be less opportunity for creative work. Jobs will be more defined, offering less autonomy and requiring adherence to more standardized procedures. It is possible that for engineers holding these jobs, work will offer more sources of stress and less job satisfaction.

-- Considerable amounts of routine data-handling will be eliminated by the establishment of shared data requirements and the automation of the transmission of data between groups. The number of jobs eliminated could be as high as 30 percent of "hands-off" labor.

-- There will be increased interdependence among various groups and functions within the company as each group spends more of its time working off of shared data, with the ability to have access to the latest designs generated by other groups.

While the reorganization of white collar work is in the early stages at the company, the reorganization of machining has been underway since the introduction of NC at the company in the 1950's. One of the areas visited by the research team is the production machine shop, where production and prototype machining work are done. Since machining deals with the manipulation of material rather than the generation of information, it is very different in a variety of important ways from engineering design work. Still, some of the same impetus behind the company-wide reorganization--the desire to move decisionmaking to as early a point in the design/build process as possible--can be seen at work in the NC area of the production machine shop.

NC and CNC machine tools, because they run off prepared programs, make it technically feasible to remove the planning of work from the shop floor. While such planning was done off the shop floor even before the introduction of NC, computerized technology substantially increases the ability of management to dictate at a very detailed level how a part will be cut. The exercise of this ability has the effect of moving many production-related decisions further forward in the organization. Although the increasing use of CNC in the production shop offers management a range of alternatives with respect to the amount of input a machinist will have on the programming and editing process, the company's general practice is to prohibit programming and editing on the shop floor in the milling operations, the core of the shop. This choice is based on certain technical considerations, such as the complexity of the part, but also on managerial preferences as to where in the organization programming work will be done. For machinists, this use of NC has the following consequences for the work environment:

-- Most NC machinists complained of boredom on the job. The long running times of many parts, combined with the removal of all planning functions to the programming department, means that skilled machinists must struggle to remain alert for problems that may develop while a part is being cut. NC has not eliminated the need for a skilled operator, yet the practice of removing a substantial part of traditional machining work from the NC operator makes it more difficult for the operator to remain engaged in the cutting process.

-- The amount of latitude which NC machinists have in the performance of their duties is significantly reduced by the practice of removing all but the most routine programming from the shop floor, and by the increased importance of various support groups to the machinists' task. This decrease in the autonomy of the machinist is a major contributing factor in the boredom which NC operators reported. Also, the latitude of supervisors is constrained because many of the production decisions formerly made by supervisors are now made by others.

-- Interdependence has increased in the machine shop. There are more support groups involved in the production of any given part, so that a delay in any one area affects the operator's ability to produce parts quickly and efficiently.

-- The ability to dictate how the machinist's job will be done makes it possible for management to track the NC operator's performance more closely. In addition, electronic monitoring makes some aspects of shop floor operations more visible to management.

An examination of the NC machine shop reveals that, even at the present moment, there are limits to the ability to fully anticipate from off the shop floor the requirements of the production process. When unplanned events arise, machinists and supervisors may intervene in order to correct a problem or improve the flow of production. Although it is the company's practice to forbid editing by operators except in certain well-defined situations, editing of NC tapes is sometimes done on the shop floor by machinists using the CNC control panel. In a significant number of cases, this editing, which has been made far easier with the introduction of CNC, takes place with the approval and encouragement of the supervisor. In these cases, supervisors reportedly consider editing by machinists necessary in order to meet production schedules.

Acknowledged procedure in the NC shop--the planning of work off the shop floor, at an earlier point in the manufacturing process--is in contrast with the informal arrangements that are sometimes made in order to expedite production. This raises questions about whether removing planning from the shop floor to the extent that the company has chosen to do so is the most efficient approach. Many machinists interviewed believed that it was not, and expressed a desire for further training in the use of their CNC machines, both out of their own interest and for the sake of expediting production. While an increased role for machinists in programming and editing may or may not be more efficient for producing any given part, the evidence from interviews with machinists in the production shop strongly suggests that it would have a positive effect on the quality of the work environment.

FOOTNOTES

1. *Aerospace Facts and Figures* 1982/83, p.116.
2. Ibid., p. 22.
3. *Barron's*, May 2, 1983, p. 9.
4. *Aviation Week and Space Technology*, March 14, 1983, p. 177.
5. *Aviation Week and Space Technology*, March 9, 1970, p. 12.
6. *Aviation Week and Space Technology*, March 11, 1974, p. 12-13.
7. *Aviation Week and Space Technology*, March 12, 1979, p. 8.

Constant Dollar Aircraft Sales
1979-1981

(1972=100)
(Millions of Dollars)

	Total	Civil	Military
1970	15,198	4,792	10,407
1971	12,391	3,920	8,471
1972	10,750	4,181	6,569
1973	12,656	5,433	7,223
1974	12,845	5,499	7,345
1975	13,022	5,147	7,874
1976	12,859	4,547	8,312
1977	13,096	4,422	8,674
1978	14,407	5,480	8,927
1979	15,150	8,126	7,023
1980	16,996	9,182	7,814
1981	18,907	8,978	9,929

Source: Aerospace Industries Association,
Aerospace Facts and Figures, 1982-83, p. 13.

8. *Aviation Week and Space Technology*, March 14, 1983, p. 167.
9. *Barron's*, May 2, 1983, p. 8.
10. *Aviation Week and Space Technology*, March 14, 1983, p. 168.

11. Aviation Week and Space Technology, March 6, 1972, p. 17.

12. Boston Globe, May 31, 1983, p. 51.

13. Wall Street Journal, September 28, 1982.

14. "The Future of CAD/CAM Integrated Systems," internal company document, p. 2.

15. "The Heart of Integration: A Sound Data Base," IEEE Spectrum, May 1983, p. 44.

16. "CAD/CAM Promises Quality, Schedule, Cost Dividends," Company's News, January 6, 1983, p. 4.

17. Ibid, p. 4.

18. Fred Guteri, "An Unanswered Question: Automation's Effects on Society," IEEE Spectrum, May 1983, p. 91.

19. Mike J.E. Cooley, "The Impact of CAD on the Designer and the Design Function," Computer-Aided Design 9(4), October 1977, p. 241.

20. "The Future of CAD/CAM Integrated Systems," p. 1.

21. Frederick J. Norton, "Interactive Graphics and Personnel Selection," in Autofact West: CAD/CAM VIII. Society of Manufacturing Engineers, conference proceedings, Nov. 17-20, 1980, Anaheim, CA, Vol. 1, p. 114.

22. Frederick J. Norton, "Selecting Personnel to Work on the Interactive Graphics System," Automation Technology for Management and Productivity Advancements Through CAD/CAM and Engineering Data Handling, Peter Cheng-Chao Wang, ed. (New Jersey: Prentice-Hall, 1983), p. 204.

23. "An Unanswered Question: Automation's Effect on Society," p. 91.

24. The company has several other NC machine shops. The practices in this one, according to to several managers, may not generalizable to the others.

25. The percentage of higher labor grades in the machine shop has increased with the introduction of NC. In particular, 62 percent of machinists were labor grade 8 and 9 in 1958, compared to 73 percent in 1983.

26. Greater difficulty in meeting deadlines may mean increased stress for the workers and supervisors rather than the deadline not being met.

The Effects of Programmable Automation on the Work Environment
A Case Study of an Auto Assembly Plant

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I. INTRODUCTION

Of all varieties of automation, none has captured public and media attention more than robots. The potential flexibility and widespread applicability of robots have fueled considerable speculation about their future influence on industry and society. In recent years, robots have begun to make their first tentative steps from the imagination and the laboratory into the factory. These robots are programmable machines with arms that can move simultaneously along a number of axes at a range of speeds, with attachments that rotate and grip like a human wrist and hand. The automobile industry has led the country in applying robots to manufacturing and uses about 25 percent of the robots in the United States today.[1] The auto company which is the focus of this study has led the automobile industry in applying robotic systems to welding operations.

The research team investigated the effects of robots on workers and supervisors in one of the company's major assembly plants. Whether observers focus narrowly on robots and the jobs they perform, or broadly on the automated system of which robots are a part, may strongly influence their perceptions of how robots change the work environment. Looking only at the robots themselves, the jobs they do, and the repairmen who work directly with them, the factory's experience confirms two common perceptions:

- Robots eliminate some hazardous and undesirable jobs. In the plant studied, a considerable number of hand-welding line jobs have been taken over by robots. These jobs were physically demanding and required operators to work surrounded by the sparks generated when a weld gun meets sheet metal.
- Maintenance workers' jobs become broader, more challenging, and more interesting after the introduction of automated systems.

However, a broader focus on the integrated system of which the robots are a part suggests some further conclusions that contradict the conventional wisdom:

- Downtime and reliability can remain significant problems two and a half years into the life of a system which integrates separate operations with computer-controlled conveyors and carriers, and connects large amounts of complex, automated equipment in series.
- The introduction of automated systems can result in an intensification of work and an erosion in the quality of life on the job. This stems from the fact that subassembly jobs are now tied into a line, the subassembly and main assembly lines are run faster, and downtime creates stop-and-go pacing which is outside the workers' control.
- There can be a dramatic increase in the stress on supervisors, especially maintenance supervisors, in a complex, automated system that suffers high downtime.
- Automation does not necessarily result in a safer working environment. At the company studied, hazards associated with hand welding have diminished, but some new dangers accompanied the introduction of programmable automation.
- Adequate training does not exist for displaced production workers to move into skilled repair jobs created by automation.

The auto manufacturer's poor financial condition and inability to spend money to maintain the system no doubt exacerbated the start-up problems of the automated welding operations. The start-up problems and managerial pressure to raise labor productivity and cut labor costs may, in turn, have increased the pressure on supervisors and production workers. However, even after the company has returned to profitability and after almost three years operation at the time of this study, downtime remains high and pressure at work remains significant.

II. STUDY METHOD

The 3-day visit to the auto plant took place in May 1983. It included an introductory discussion and tour of the plant by the Personnel Department and a brief interview with the plant's Manufacturing Engineering Manager on the third day. The research team spent the remainder of the 3 days interviewing workers, shop-floor managers, union stewards, and union committeemen who work in the automated welding facility--the "body shop."

Throughout the visit both management and union cooperated completely with the research team. The plant management permitted unrestricted access to the body shop. The superintendents in the body shop, in turn, allowed unrestricted access to supervisors and workers. This access included the freedom to move independently around the shop floor and to speak with workers on break at their work stations. Only through this unique cooperation was the research team able to gain, in a brief time period, a detailed knowledge of how automation affected individual jobs and how the workers on these jobs perceived the effects of the system.

During the 3 days, the research team interviewed:

- welder repair and production superintendents.
- two welder repair general foremen and one welder repair foreman.
- one production general foreman and one production foreman.
- three welder repairmen.
- 19 production workers (6 first shift workers were interviewed for more than an hour at the union hall and an additional 15 to 45 minutes on the job; the remainder were interviewed either in the union hall or in the plant).
- the production and skilled trades' union stewards on first shift, and the production and skilled trades committeemen.

- a number of other managers, union officials, and workers with knowledge of some aspects of automation and the body shop.

The group above represented about 30 percent of the production workers, 15 percent of the skilled tradesmen, 70 percent of the supervisors, and all of the union officials with first shift responsibilities in the part of the body shop containing robots.

Interviews with supervisors, union officials, and workers were open-ended and loosely structured, based on a prepared interview guide. The interviews at the union hall were taped, with the consent of the interviewees. The quotations used are from the taped interviews or from notes taken during the meetings by other than the principal interviewer. The research team conducted followup interviews of 15 to 45 minutes with certain individuals on the second and third days. Additional followup interviews were conducted with union officials and body shop supervisors over the telephone. The corporation's Director of Manufacturing was also interviewed over the telephone.

The purpose of this report is to evaluate the impact of programmable automation on the work environment, not to analyze the overall value or economic benefit of automation to the company. Given this mandate, an important part of the study has been the exploration of worker and management perceptions of the work environment changes resulting from automation, perceptions which, by their very nature, are subjective.

II. BACKGROUND

The Auto Industry

The auto industry is increasingly competitive, sensitive to economic cycles, and in a period of rapid change. U.S. auto manufacturers have faced a difficult decade adjusting to fundamental changes in marketing and manufacturing of their products. Competition has intensified as imports, which in 1972 were 14.3 percent of total sales, rose by 1982 to 26.4 percent of new cars sold in the United States.[2] Production technology has evolved rapidly to accommodate shifts in consumer tastes toward smaller, lighter, and more efficient designs.

The trend toward smaller, fuel-efficient cars began after the oil price shock of 1973 made fuel efficiency an important criterion for purchasing a new car. Detroit responded slowly to this change for a number of reasons, including an inability to use existing production lines to make smaller cars. As a result, a large percentage of the U.S. auto market was captured by foreign producers.

As U.S. manufacturers made their cars smaller, the basic structure of the auto body itself changed. Traditionally, an auto body was lowered onto a heavy steel chassis. The loads and stresses of the car were primarily carried by the frame underneath the body, not the body itself. By the mid-1970's, Detroit downsized its cars and began manufacturing compact cars with load-bearing "unit-bodies." Since the unit body bears considerable stress, the underbody could be made much lighter, reducing the total weight of the car.

This change in body type from steel rail chassis to unit-body construction required parallel changes in automobile production methods. While mechanical fasteners held together the traditional rail chassis, spot-welds join the pieces of the unit body.

> With unit-body construction came increased demand on the consistency of stamped sheet metal, which now bore more load than before. The sheet itself was more conducive to welding; the number of mechanical fasteners (and their installation tools) was reduced while spot welding guns, and robots to repetitively weld them, increased.(3)

This change in production methods meant that the process of making an auto body became more uniform and amenable to automation. The parts of the car to be welded by robots, however, must be precisely positioned by a fixture or "gate" so that the welds are placed correctly.

The Company's Position in the Industry

The auto manufacturer's sales declined from $16.7 billion in 1977 to $9.2 billion in 1980.[4] The company was particularly affected in 1979-80 by its inability to produce a sufficient number of small cars and by consumer concerns about its viability. Although the other major U.S. manufacturers have also been adversely affected by changes in consumer demand, the firm investigated is smaller than its two major domestic competitors, and it maintains that, as a result,

> ...(it) is at a competitive disadvantage in responding to substantial changes in consumer preferences or government regulations that require major additional capital expenditures. Moreover, adverse economic developments which could be absorbed by companies with greater resources can be expected to have a more severe effect on (the company) because of its recent losses and small size. (5)

Due to these disadvantages and longstanding management problems, the firm nearly went bankrupt in the late 1970's. Extensive Federal loan guarantees, a change in management, employee wage concessions, and concessions from suppliers prevented bankruptcy and the company's fortunes are now improving. The company had sales of over $10 billion in 1982,[6] and repaid some of its emergency loans earlier than required.

Labor Relations

Due to its restructuring and the recent recession, the company has reduced its hourly labor force since January 1979 from 104,854 (of which 10,122 were on layoff) to 80,153 (35,028 on layoff) (figures as of June 3, 1983).[7] During this period, the firm has closed or consolidated approximately 20 manufacturing plants.

Company employees made large wage concessions to aid its recovery: currently, its workers earn approximately $2.00 an hour less than those at other major domestic automakers. Now that the manufacturer is profitable again, workers are demanding that their wages be raised to the industry average. The Wall Street Journal reports,

> The union is seeking a quick raise mainly because rank-and-file sentiment for a wage boost currently is high. (The company's) renewed profitability and its plans to pay $400 million of its federally guaranteed loans today, ahead of schedule, are fueling worker demands.(8)

IV. THE COMPANY'S STRATEGY FOR IMPROVING PRODUCTIVITY

During its recent recovery, the auto company has placed great emphasis on increasing productivity. According to the company's Vice-President of Manufacturing, higher productivity has been achieved both by "organizing productivity"--increasing the efficiency and cost-effectiveness of the labor force--and "buying productivity"--

installing robots and other automation. In the words of the manufacturing vice-president, "You can either buy productivity or you can organize it. Sometimes I buy it, when I buy robots and other automation. But mainly I organize it."[9]

In its efforts to "buy" productivity, the company has played a leading role in implementing programmable automation. In 1978, the company was the first U.S. auto manufacturer to introduce the "Robogate" welding system which is the centerpiece of the automation at the plant studied and is now considered state of the art in the industry. The company continues to improve the system and to automate an increasing variety of operations throughout its plants. The Director of Manufacturing Engineering maintains that, "In each plant as new products are launched, the level of automation, the level of sophistication increases." A plant scheduled to begin operation in October 1983, for example, had twice the number of robots as the plant studied. The new plant includes spray-painting robots (which will soon be installed in the plant visited), a monitoring system to help body shop repairmen with the identification of problems, and the company's first application of automated visual inspection. Over the next 4 years, according to the president of the company's North American automotive operations, the company intends to spend $6.5 billion on capital expenditures.[10]

In the immediate aftermath of its near bankruptcy, the company's "organizing" productivity efforts centered on consolidating operations, closing a number of plants, and gaining wage concessions from employees.[11] The corporation's breakeven point fell from 2.3 million units in 1980 to 1.1 million units in 1982.

The Director of Manufacturing says present efforts to increase productivity have focused on combining skill classifications, automating labor-intensive operations, and reducing inventory on the shop floor. He maintains that combining classifications spurs productivity by increasing flexibility when workers are absent, and by eliminating time during which basic tradesmen might be waiting for a problem for which they are responsible:

> As you look at work assignments, one of the biggest areas we can improve our productivity is in the classifications. We're going to save some heads and we're going to be a lot more efficient with the ones we have.

Ultimately, the director continued, the company is looking at the possibility of having only two broad skilled trades, electrical repair and machine repair.

Current efforts to reduce labor costs are directed at the trim and chassis operations. The manufacturing engineering director explained, "We're rapidly moving towards trim and chassis, that's where the highest concentration of manpower is." He added that while some observers say such automation eliminates jobs, in his opinion it is the only way to guarantee that any jobs remain: "I hear people talk about the jobs these robots displace but productivity is going to keep us competitive. If we'd gone bankrupt, obviously they'd all be out of a job."

The push to reduce inventory on the shop floor has its origins in the effort to remain competitive with the Japanese, according to the company. The Japanese have popularized the "just-in-time" delivery or KanBan concept, in which supplies of parts arrive immediately before assembly and are not stored on the premises in volume. The manufacturing engineering manager said just-in-time delivery eliminates costly inventory which occupies about 20 percent of the floor space in a traditional plant. He added that just-in-time delivery improves quality in a number of ways. When something goes wrong with a part, managers find out right away, rather than hours or days later when they come to the end of their inventory. As a result, they can immediately inform the supplier or the supervisors of the operations that produced the part, before large numbers of low quality parts are made. Just-in-time delivery also reduces damage inflicted in storage.

The director also suggested that reducing inventory in the plant can improve productivity and quality on the assembly line. Without inventory between separate operations, workers cannot speed ahead and possibly jeopardize quality. In addition, workers must work consistently throughout the day, and cannot take breaks while parts they have stored feed into the line beyond them.

V. THE BODY SHOP AT THE PLANT

The Plant

The company built the plant studied in 1951 to produce tanks for the Korean war. The company began converting the plant to automobile production in 1955, and produced its first car at the facility on April 30, 1957. In 1976, its most productive year, the plant produced over 248,000 cars and, to date, the plant has manufactured more than four million automobiles total. Production in the last 3 years has equalled 139,850, 202,259, and 172,250 cars, respectively.

The plant now manufactures sedan and wagon versions of a car designed to help capture part of the market for compact cars. The plant currently produces at a daily rate of 59.1 cars per hour for 18 hours, or over 1,000 cars per day. The plant has back orders for one month of production and will remain on its present shift operation (two nine-hour production shifts, and one overlapping eight- to ten-hour maintenance shift) at least until September 1983. The present daily production and weekly shift rotation is equivalent to an annual production rate of 280,000. The company expects to manufacture 244,000 cars here in the 1984 model year (August 1983 to July 1984). The plant presently employs 4,000 workers, including 3,500 hourly workers of whom 300 are skilled workers.

The body shop consists of two main areas, framing and finishing. This study is concerned only with the framing area in which sheet metal parts are welded into a car body, not with the polishing, grinding, etc., which is done on the finish side.

Welding Before Robogate

Before the introduction of the automated welding system called Robogate in 1980, those in the plant referred to the body shop as the "jungle"--a tribute to the dozens of hand-welding guns that hung along the side of most welding operations, their supporting and electrical wires draped around them like vines. Sheet metal components were held together for welding on fixtures called gates. These gates cradled the sheet metal parts, duplicating the exact shape of the car body, while a human welder moved the welding gun over the designated surfaces joining the various parts together.

Before Robogate, the body shop contained two "side-gate" loops (one for each side of the car), several small subassembly areas, and a main frame line. The loop and main frame conveyors moved at a maximum pace of 60 cars per hour.

In each side-gate loop, individual car sides would be carried past a series of work stations by one of 18 gates. At each station along the loop, workers placed subassembled and some individual parts in a gate before spot welding them by hand. On the outside of the loops, workers welded the subassembly parts (e.g., the wheel-house, quarter panel, and panel dash) and placed them into piles by their machines. About 35 automatic welding machines and a large number of hand weld guns were used for these subassembly operations. In another small area to the side, workers welded the front half of the floor pan to the back half in a press-welder to make part of what is now called the underbody.

At the beginning of the main frame line, gates for each side of the car were "married" together with an underbody carrier, the "body truck," to make a larger gate, the shape of the entire body. Hand-welders then added stabilizing welds to join the sides, floor pan, engine compartment, and roof. Because different sides and bodies had been held in place by different gates, the dimensions of the frames coming out of the body shop varied slightly. In addition, the dimensions of each gate had to be checked several times a year against a master body. Because of the variability among different gates, it was a major advance when the number of gates was reduced from 38 to 18 for the 1976 model year. At the same time, 13 robots were introduced. These robots were put on what is called the automatic respot line (ARS), where "respot" welds are added to the car body to make it mechanically sound.

The operations in the body shop before Robogate were not highly interdependent. Damage to welding equipment, for example, would interrupt production briefly and in a very limited area: workers simply used backup guns while repairmen fixed their first-line equipment. If an accident damaged a gate, it could be removed from the side-gate loop and realigned. Even damage to the robots in the ARS line would not halt production, which could be directed to a manual bypass line. Only problems with the conveyors could paralyze a significant fraction of the system.

The Automated Body Shop

In response to the increase in consumer demand for smaller cars, the company designed the car produced at the plant visited. The car required new production facilities and retooling due to substantial design differences compared to earlier models. The bulk of the $60 million retooling of the plant, the most extensive since the original conversion to automobile production, was directed to the body shop.

The automated body shop has three basic areas. In the side aperture area, parts stamped from sheet metal are welded together to make the right and left sides of the car; in the underbody area, the floor panel, the bottom of the engine compartment, and a number of other parts are joined; and, on the main frame line, the sides, underbody and roof are joined into the car body, which then goes through the respot line where hundreds of additional exterior welds provide the car with its structural rigidity. This study is concerned with side aperture and the main frame line because these areas contain robots.

The Robogate System

At the heart of the automatic frame welding system is the main line Robogate itself, a single fixture or gate that holds the sides, underbody and other parts in place while robots apply spot-welds that set the dimensions of the car. The automated system was modified and installed by the manufacturer for the introduction of the new car body at the beginning of the 1981 model year

Robogate has a number of major technical and economic advantages over previous methods of welding. First, dimensional consistency of the body is assured because only a single gate is used for each car type. Second, Robogates improve the strength and quality of welded frames because robots place their welds in the same place in each body. In the words of the plant's Manufacturing Engineering Manager: "(There is) less fluctuation due to worker control items." Third, Robogates make it possible to automate the entire respot operation, because once through the Robogate, no fixtures are left around the body, and respot robots have a clear path to the car. Fourth, Robogates reduce retooling costs substantially. In the old body shop 18 gates had to be purchased for each model. In a fully automated framing operation only two complete gates need to be changed (one for sedans and one for wagons) plus some fixturing and clamps in ARS and side aperture. With the advent of programmable weld-controllers, robots can also weld at a number of pressure and temperature combinations. This allows the use of more galvanized metal than in a hand-welding body shop. Galvanized metal need not be coated with primer and reduces production costs further down the assembly line.

Side Aperture

In side aperture, the left and right sides of the body each progress through five automatic welding machines, six robot respot welders ("east and west respot"), and two "pretack" robots. The automatic welding machines can apply a large number of welds at once, while robots apply only one at a time. On the other hand, unlike the robots, automatic welding machines are "hard" automation which must be heavily modified or scrapped each time there is a change in the design or dimensions of the car. Workers on the automatic welding machines lift several parts off racks or the floor and place them into a fixture, then hold down a palm button for several seconds while automatic clamps close and the machine welds the parts together. They then lift the welded part out of the machine and load it onto a hook on a conveyor or gravity feed.

At the first station in side aperture, a worker makes the tail-light closure at one automatic welding machine. A gravity conveyor then carries this part to the next work station where it is attached to various other parts of the car side: e.g., the roof rail, the B post which is located between the front and back windows, and the hinge pillar. These tasks are performed sequentially by two pairs of workers at two automatic welding machines. The machines are connected by a gravity conveyor with 18 hooks. From the second of the two machines, workers load the side aperture onto an automatic conveyor which carries the sides to another welding machine where two other workers attach the door hinges. After this the side apertures are loaded onto a carrier called a monotractor that rides on an overhead mono-rail. Each monotractor has an independent, electronically operated and signal-controlled motor and is programmed to stop at various weld stations. Carried by the monotractor, the aperture progresses through the six respot robots before moving to a station where workers attach the wheelhouse and rail assembly loosely to the side. Next, two workers add sealing tape to prevent leakage from the body when it is in service. Finally, the completed aperture passes two more robot-welders (which tack-weld the wheel house and rail assembly to the rest of the side) before being carried by a monotractor into the buffer or directly onto the main frame line. Side aperture can now produce over 100 cars per hour.

The Main Frame Line

At the beginning of the main frame line, the two sides and the underbody are "toy-tabbed" together by a group of seven workers: these workers hammer tabs on each part into slots in adjacent parts to hold the body loosely together. Next, an 8-robot Robogate and six respot robots apply 56 stabilizing welds to establish the dimensions of the frame. A group of about 10 workers then manually welds on the roof, and adds additional interior welds.

After this the bodies move into an expanded automatic respot line--called the "turkey farm" because the robots welding look like turkeys pecking at their food--where 32 robots apply a total of 676 welds to sedan bodies and 714 welds to wagons. The motions of the ARS robots are far less complex than those of Robogate robots because respot robots need not navigate their way around large fixtures. Most ARS robots apply a large number of closely-spaced welds on one or two seams. The final spot welds are applied on a manual respot line. On this line workers holding traditional weld guns weld places the robots cannot reach or have missed. The automated main frame line can produce over 110 cars per hour.

The Buffer

In addition to the assembly areas, the automated body shop contains a multistory 45,000 square foot buffer which holds a total of over 120 underbodies, finished bodies, and side apertures of each kind. An overhead Webb conveyor (referred to in the body shop by its manufacturer's name) carries the parts and assembled bodies to and from the buffer, while traslas (stationary fork lifts) raise and lower them.

The buffer theoretically provides insurance in case either the subassembly or final body assembly operations suffer downtime. Any third of the body shop can continue for up to 2 hours (depending on how full the buffer is) if problems occur in one of the other two-thirds. In practice, according to a production general foreman, the buffer often provides much less than 2 hours insurance because downtime tends to concentrate in one area, rather than being evenly distributed throughout the system. If a subassembly area goes down a lot, the parts produced by that area will be in short supply in the buffer. If that area suffers a further breakdown, the main frame line must soon stop. On the other hand, if the main frame line goes down repeatedly for a few weeks, the buffer will be full of side apertures and underbodies. When the main frame line comes to a halt in this situation, the subassembly areas must also stop because there is no more room in the buffer. The rest of the plant can theoretically operate for as much as 2 hours when the body shop goes down if the buffer is full of completed bodies and operating.

The buffer also provides less insurance against breakdowns than it should in theory because of its unreliability. As often as not, according to body shop supervisors, when parts need to be stored in or taken from the buffer, electro-mechanical problems make this impossible. The company's Director of Manufacturing Engineering adds "our high-rise storage systems have given us more downtime than our sophisticated robotic equipment." For this reason, and to reduce inventory, the company plans to remove the buffer and replace it with winding tracks of underbodies, and winding conveyors of side apertures and roofs. Unlike the present buffer, this storage system will not require parts to be lifted to and down from storage spaces above the floor. The only buffer of welded bodies will be a part of the main line which winds between the manual respot and finishing operations and holds about 25 to 50 cars. By keeping bodies in sequence between welding and finishing operations, downtime which results from electrical and computer problems experienced putting frames back in sequence on the way out of the buffer will be eliminated. On the other hand, with fewer stored parts, breakdowns in one area could more rapidly paralyze other areas of the body shop, and even the rest of the plant. The production superintendent believes, however, that the buffer breaks down so frequently that its elimination may not increase the total downtime in the shop.

Subassembly Banks

In the body shop, some parts are stored between successive subassembly operations in "banks." When a breakdown occurs, stored parts are fed into the line beyond the breakdown and production proceeds smoothly. Because the storage of parts reduces a system's vulnerability to breakdowns, the company installed additional gravity feeds in subassembly areas during the early, highly unreliable operation of Robogate. It also allowed workers to place piles of parts on the floor when the feeds and conveyors between operations filled up. The production supervisor explained that, "...the more complicated the equipment you've got, the more banks you get. The equipment started breaking down, so we built ourselves banks to protect ourselves." More recently, these feeds have been removed and the space where many of them stood has been taken up by the automatic welding machine which attaches the door hinges.

In addition to insurance for the company, parts storage on the line permits workers some control over their work pace. Before Robogate, subassembly workers could work more intensely during part of the day and complete their production quota in considerably less than the allocated time. In the eyes of the Director of Manufacturing Engineering, however, large unofficial banks increase inventory and lengthen the time between the occurrence of a quality problem in subassembly and its detection down line. In addition, the existence of banks suggests to upper management that jobs have not been timed properly. Theoretically, each job should be structured so that if standard methods are used, and the worker is quality conscious, banking will be impossible--the operator should have to work consistently the entire day. The company therefore designed the body shop to limit the space available for storing parts. There is limited room between machines and the gravity feeds and conveyors which separate sequential operations contain only about 18 to 30 parts. As a result, workers can, without placing parts on the floor, earn themselves breaks of no longer than 15 to 25 minutes. Some subassembly jobs, in fact, have no bank (e.g. the taping and hinge-welding operations) and have taken on precisely the character of line jobs. Furthermore, the company prohibits workers from creating unofficial banks by the sides of their machines. The ultimate goal, according to the production superintendent, is to establish a situation where "You flow like a river with no lakes. That's what we're trying to do, get rid of all the lakes."

In summary, four important largely technical changes have accompanied the introduction of Robogate: 1) large numbers of line and subassembly hand-welding guns have been eliminated; 2) the top speed of the two subassembly areas and the main line has risen from 70 to 100 and 110 cars per hour, respectively; 3) the integrated nature of the automated subassembly and final assembly lines makes the system more vulnerable when individual pieces of equipment break; and 4) the rhythm of subassembly jobs is now regulated tightly by machines. This is partly a result of system design and partly stems from management policies on shop-floor inventories.

VI. EMPLOYMENT IN THE BODY SHOP BEFORE AND AFTER AUTOMATION

Skilled Tradesmen

Automation of the frame-welding operation has increased the number of skilled workers in the body shop from about 65 to slightly more than 100. All new hires have been welder repairmen: before Robogate there were 26 welder repairmen in the body shop; today there are 76 (32 on first shift/28 on second/16 on third), down from a peak 96 on roll when the system began. There are more welder repairmen because of the increase in robots and other automated equipment which they service. The extra 20 were brought in originally to help smooth early operation and because the company was not sure how many the system would require.[12] The number of toolmakers employed has fallen, since 1980, from between 15 and 20 to 10. This decline resulted primarily from the reduction in the number of gates and other precision fixtures that toolmakers serviced. Some of this work has also been taken over by welder repair. The number of workers in the body shop from each of the other basic trades has remained approximately unchanged. In total on all three shifts there are still about nine electricians, five pipefitters, and eight millwrights.

Production Workers

Plant management feels automation and the design of their new model have changed the duties of different parts of the body shop so much as to make quantitative comparisons of production employment in the framing area before and after 1980 misleading. Workers, production supervisors, and union officials interviewed, however, pointed to a significant decline in the number of framing side production workers since 1976, the year the plant received its first robots (and when it last had daily production approaching what it is today). At the time of this study, the framing side of the body shop employed 105 production workers on each of the first two shifts: 31 in underbody; 29 in side aperture; 22 on the Robogate line; and 23 in manual respot.

VII. RELIABILITY AND DOWNTIME

As a result of automation, labor productivity in the body shop is now significantly higher than it was in 1976. In addition, workers and management both feel quality has substantially improved, largely because robots place high quality welds in the same place every time (when the weld guns operate properly). A welder repair supervisor elaborated:

> (With a) man welding, sometimes they don't feel well or there is absenteeism--the guy filling in doesn't do as good a job. You don't have total control of welding....As far as scheduling (of different types of welds) is concerned--there are differences in pressure, differences in weld time, differences in heat. With men we used to use only two variations, and even then people would forget to hit the button.

Because of the automated body shop's high productivity, improved quality, and low retooling costs, company management regards the system as a success. On the other hand, the high and variable downtime of the system is a serious problem and has a direct and negative influence on the quality of life at work for both supervisors and production employees in the body shop. Because the focus of this study is on the work environment and automation, downtime will be discussed in some detail below. The cost savings resulting from greater labor productivity and reduced retooling costs, however, will not be analyzed further. This is not meant to reflect on the system's overall value to the company, but rather is a function of the study's mandate.

The designers of the automatic framing system anticipated downtime of 20 percent, according to the welder repair superintendent in the body shop. Downtime currently fluctuates between about 17 percent and 22 percent--substantially lower than during the hectic early operation of the complex system.[13] The manufacturing engineering manager appeared satisfied with the system's performance: "Most automation systems, you aim for somewhere in the range of 15 to 20 percent downtime. Overall, we operate within that range." The corporate manufacturing engineering director says the plant's experience has been similar to that in the company's other automated welding operations: "(The body shop at the plant has) had some good months and some months when we had more downtime than we anticipated."

Before the installation of Robogate, downtime in the body shop averaged 3 to 5 percent, according to production and repair supervisors who were working at the plant in 1979. A maintenance general foreman who worked in the body shop for 4 years as a welder repairman before 1980 said the main frame line might go down twice a day for "10, maybe 15 minutes," when side-gates and the body truck failed to unmarry. He added, "I can't remember subassembly ever holding up the (main frame) line."

Despite its downtime, the automated body shop generally matches the production in the rest of the plant because of the higher throughput of its lines. The rest of the plant usually operates at between 59 and 64 cars per hour and cannot go above 70 cars per hour, while all parts of the body shop can go as high as 100. At the present time, the assembly line beyond the body shop runs at a standard rate of 59.1 cars per hour while side aperture and the main frame line run at 78 cars per hour.

The principal causes of downtime in the automated framing shop have been the conveyors which carry parts down the line and to and from the buffer, and the buffer itself. The most frequent mechanical problems arise with the traslas that raise and lower parts from the overhead Webb and the buffer. In addition, the photocells on the line sometimes miscount the number of carriers that pass them and tell the computer to let too many bodies fit between two points. As a result, the carriers become jammed and will not move properly. The monotractors in side aperture also cause some downtime. The buffer and the monotractors have not been designed into the company's new plant which was scheduled to open in October 1983.

Although system downtime has decreased in the last 12 months, it remains to be seen whether it will continue to drop further. The highly integrated nature of the automated body shop leads one to expect downtime above that in the traditional body shop--hence the projections of high downtime by the designers of the system. Moreover, downtime has hovered around its present level for the past 6 or 7 months. A production general foreman felt that:

> ...(downtime's) kind of stabilized now. We don't run gaps (carriers through the line without bodies) anymore, but we still don't gain significantly (over the other parts of the plant). It's a crazy animal."

The company's manufacturing engineering director believes the debugging period in the plant is over. He maintained that problems specific to start-up operations usually last less than a year: "If anything's going to go wrong, it's going to go wrong in the first 60 days."

While system downtime has been high, the robots themselves have performed extremely well, averaging more than 95 percent uptime. As one tool engineer described it, "you can get the individual Unimates working." The occasional problems with the robots themselves usually stem from problems with the hand-gear train, which has substantial torque on it when the robot arm is fully extended. There are continual problems with the wearing of the weld tips at the end of the robot-welder arms, but this malfunction is common to all weld guns and has nothing to do with the robot.

VIII. THE IMPACT OF AUTOMATION ON THE NATURE OF JOBS

Supervisors

> Andy Jones, Andy Jones, we have a crash between a 41 (sedan) and a 45 (wagon) out here on the Webb. Bring hammers, millwrights, and blow torches so we can untie this unholy mess.
>
> That doesn't sound too good.
>
> You don't say.

To the outside observer, life in the body shop appears to be one long series of reactions to unanticipated problems. On the first day of the research team's visit, two wheels on a trolley carrying welded bodies to the finishing operations came out of their track, and only a "mule train"-- workers pushing cars by hand to the finishing line--kept the line beyond the body shop moving. On the second day of the visit, an hydraulic pipe burst on the tabbing line, spraying one of the workers and taking 45 minutes to fix. On the third day, the crash described in the first paragraph of this section took place. In the words of one production supervisor, "You're dealing with a system that you don't have any control over. It controls you. You react to it. It sets the parameters and you have to fit yourself into it."

The frequent crises in the body shop put substantial pressure on those responsible for operating the system and, in particular, those responsible for maintaining it.

Welder Repair Supervisors

In the body shop, welder repair supervisors have chief responsibility for keeping the capital-intensive and technically complex automated framing system going. Welder repair is responsible for all the welding, electronic, pneumatic, and robotic equipment except the buffer, which is maintained by four electricians.[14] On the two production shifts, each of the three welder repair supervisors (who are part of lower-level management and are not included in the bargaining unit) has the responsibility for overseeing maintenance in one of three areas: underbody; side aperture/Robogate/ARS; and the metal finish side of the shop. The supervisors must also order parts and determine with production foremen when production can begin again after a breakdown.

Welder repair supervisors feel they work under extraordinary pressure. The most concrete evidence of this pressure is the high turnover among this group since the automated system went into operation. In the body shop as a whole (including the metal finishing side), there are 11 welder repair supervisors, in total, on all three shifts (one superintendent, three general foremen, and seven foremen). In the 33 months since the system began operating, 19 supervisors (16 foremen, 1 general foreman, and 2 superintendents) have either resigned, transferred, or been demoted, according to a body shop supervisor. Of these 19, only 7 are still with the company. Half of the 16 departed or demoted first-level supervisors have left the side aperture/Robogate/ARS area. Given that there are only two supervisors (one on each shift) in this area at one time, this amounts to an annual turnover rate of about 150 percent.[15]

Welder repair supervisors interviewed repeatedly confirmed that pressure on the job had increased substantially since the introduction of Robogate. One general foremen said, "Oh yes, yes (there is more pressure). This has been the hardest 3 years of my life. There isn't any relaxation...I've walked out of here and sat in my car, unable to move, getting myself together." The welder repair superintendent said, "From what they tell me this is one of the worst jobs in the corporation as far as pressure."

The lack of desire among hourly repair workers to move up to foreman is further evidence of the high pressure on supervisors. The last time welder repair needed another supervisor, management asked every qualified welder repairman (about 25 people) to take the job. Of the 25, only the man with lowest seniority, a 22-year old, would take it.[16] Two weeks later, a follow-up telephone call to the plant revealed that this individual had submitted his resignation the previous day because, according to the superintendent: "He thinks about (his job) as he's driving home. His wife noticed the change. He never believed it could be this way." The superintendent and general foreman persuaded the foreman to stay by relieving him of some responsibility and shortening his work week. With reference to the difficulty of finding new supervisors, a general foreman explained: "It (the pressure) did take its toll. On good people, smart people. No babies. There is no one who will upgrade anymore in this department."

Interviews with operations management and welder repairmen in the body shop revealed two distinct views concerning the origins of pressure on repair supervisors. While distinct, these perspectives are not inconsistent. One view, expressed by the superintendent and some other supervisors, emphasized the technical characteristics and design of the framing operations. In this view, the integrated nature of the system makes downtime extremely costly, and the complexity of the automated equipment makes repair work far less straightforward than in the past. Combined with the pressure on a struggling company in an increasingly competitive industry, these characteristics of the technology place stress on those responsible for maintaining the system. A second view accepted most of this analysis but regarded the pressure from superintendents and upper management as the core reason for the stress of supervisors' jobs. This pressure is particularly damaging because it makes a complex system all the more difficult to deal with. In this view, welder repair supervisors are sometimes told to take ill-considered steps (or prevented from making necessary repairs) and then given responsibility for the consequences.

Both perspectives recognized the interdependence of different frame assembly operations as a critical aspect of the pressure on supervisors. When there is a problem with one part of the system, either a third or all of the body shop can be paralyzed quickly The welder repair superintendent explained, "Everything is tied together now. When one part goes down, it affects many more operations than it did in the past. If one limit switch goes down in ARS, you can tie up the entire line." A production supervisor put it bluntly: "If one system's dead, the whole system's dead after a while."

While the main frame line before Robogate was equally integrated, its component parts were simpler and far more reliable. Moreover, backup welding guns and spare gates could replace front-line equipment when problems occurred. A maintenance general foreman who spent 4 years as a body shop welder repairman before 1980, and 2 years as a welder repair foreman after the installation of Robogate, said:

> You didn't have a robot. You had a portable weld gun with a cable, the gun itself, and a few air hoses. The biggest problem was the new cables which were too stiff for the operators (making the gun difficult to maneuver)...You had backup guns just about everywhere...If you had a problem with a gate, you could flip it off the side and into the repair area.

By comparison, according to supervisors in the body shop, the new equipment requires far more skill to repair. While before they could manage with two or three individuals who understood electronics, now the system demands such an understanding for the bulk of problems encountered.

The expense of the equipment adds a further source of technical pressure. Thousands of dollars worth of damage may be done if a supervisor, in haste, misdiagnoses a problem. A welder repair supervisor commented, "If I do not grasp the situation immediately, I could destroy a hand-gear train... All it takes is one push of a button. In the last three weeks, I lost two hand-gear trains." Apparently, after an emergency stop, robots returning to their rest position took the most direct route (as they are supposed to) and hit the Robogate fixtures. Each hand-gear train costs $6,500.

While the pressure may be greatest during breakdowns, it rarely disappears because problem detection is much more difficult with the automated system. The constant watch for reliability problems makes it difficult for repair supervisors to be "at ease". According to the production superintendent:

> Automated equipment makes the supervisor's job much more difficult. You have to keep checking: did the gun misfire, did the weld hold. In the old days, either the gun misfired or it didn't. And the operator would call you. Now, most of them won't tell you. They want to keep the line going.

A welder repair general foreman concurred:

> ...if they (the robots) get off a flange, or they skip a program, they won't tell anybody, that's the disadvantage. They have to be watched...There's things that can happen, that are lurking. It's follow-up, follow-up constantly. You can't relax altogether and rely on it.

The danger of injury adds further stress to the welder repair supervisor's job. All parties in the plant expressed the opinion that the danger to welder repairmen may have risen somewhat in the last 3 years. Some of the injuries to repairmen have been quite serious. A welder repair general foreman related a recent incident:

> Worrying about people getting hurt is a pressure. I fractured my skull on a Robogate trying to get six bodies through by midnight because that was the edict. I hit my head on the corner of a control box. I felt like I had a hole in my head.

In the view of all supervisors interviewed, the design and technical characteristics of the automatic framing system result directly in stress for repair supervision. Some supervisors and welder repairmen, however, believed management pressure, not the technology, to be the major source of stress in the body shop. They regarded upper level management's failure to understand the system, and strong push for high productivity (during the manufacturer's transition back to profitability) as responsible for most of the tension felt by first and second level supervisors. One former supervisor stated, "(the foremen) take all sorts of abuse. You wouldn't believe the abuse they take... They have responsibility, plenty of it, but no authority."

Pressure from upper management is felt most directly during breakdowns. According to several supervisors, any time the Robogate line looks as if it will be down for more than a few minutes plant management must be informed. Often a member of the front office staff will come to the shop to observe repair work in progress.

The superintendent does not believe stress results from misplaced management pressure. Rather, he believes the new system demands that foremen be pushed hard; they, in turn, push hourly workers hard. In his view, supervisors must not only follow up technical problems and be willing to take responsibility when breakdowns occur; they must also get repairmen to take decisive action:

> There's something about this system that makes you push (your repairmen). You have to jump on it when something stops--you can't have a guy in a haze...We had a lot of (supervisors), we just had to babysit 'em. It kind of bled through their people. If foremen and their people both have that problem, you're dead.

An obvious--and important--question is whether or not the pressure on welder repair supervisors will continue if downtime diminishes. There are at least two reasons why one might expect it to improve: the increasing knowledge of welder repairmen, and the possibility of establishing a stock of spare parts and introducing preventive maintenance as the company's profits increase.

However, there are also a number of reasons to expect the pressure on repair supervisors not to diminish even if downtime is cut further. First, despite a significant drop in downtime during the last 2 years, the welder repair supervisors themselves do not believe the stress on their job has dissipated much. Nor does the welder repair superintendent expect the pressure to disappear:

> The pressure's there. It's going to be there. It's not going to change. If anything, as the line speed goes up and (the company) improves its situation in the marketplace and wants more cars, it'll get worse. It's not spiraling down, it's spiraling up. It's not going to get any better.

The fundamental reason pressure on repair supervisors may persist is the design of the automated framing system. The prevalence of interconnected electronically-monitored and computer-controlled transport systems, and the serial configuration of complex equipment in the body shop mean that when problems do occur, pressure to get the system moving will remain intense--much more so than when repair work consisted primarily of weld gun maintenance and periodic realignment of gates.

The stress of repair supervisors' jobs may increase if management proceeds with its effort to eliminate inventory--subassembly banks and the buffer--on the shop floor. With smaller banks in subassembly, problems with side aperture machinery will quickly halt production in one-third of the automated shop. The production superintendent recognized the potential pressure associated with eliminating banks in subassembly: "At the present time, he (the production worker) is able to bank. But he won't be...It'll put a tremendous amount of pressure on those of us who have to keep the equipment going."

The elimination of the buffer may get rid of some of the present causes of downtime, but it will also make solution of problems that do arise even more critical. A welder repair supervisor claimed the cost of Robogate downtime per minute would increase to over $1,100 from the present $750. The supervisor also said that the removal of the buffer would leave only about 25 minutes worth of production stored between the framing and metal finish sides of the body shop. The Director of Manufacurting Engineering, however, said that the elimination of the high-rise buffer at another plant has worked well:

> What we find is, the urgency of getting it fixed, it's done with more speed because of the urgency. I'm not sure the pressure we're putting on ourselves for more uptime isn't what we should have been doing anyway.

Production Supervisors

The first shift production supervisory staff in the part of the body shop with robots consists of two foremen (one in side aperture, and one on the Robogate/ARS line), one general foreman, and one superintendent (who has responsibility for the finishing and assembly operations in the body shop). Because production supervisors' responsibilities are more managerial than technical, automation has not placed as much pressure on production foremen as their maintenance counterparts. Production supervisors are not directly responsible for repairing the system, but rather for quality in their area, and for getting hourly workers to perform according to standard and to work safely. They are also responsible for shifting workers around in the event of a bottleneck or breakdown, and for keeping the line going as much as possible when problems occur.

Compared to welder repair supervision, there has been very little turnover of production supervisors. In over two and a half years, only two foremen and one general foreman have resigned, been demoted, or been fired.

While pressure on production supervisors may be less than on maintenance supervisors, it is still substantial. According to the production superintendent, the pressure is "about doubled" in comparison to what it was before 1980. He then described the fate of one foreman: "I had a general foreman with...what did they call it, the medical term for all messed up and ready to flip his lid...severe depression. It's a pressure job." As with welder repair foremen, it is not easy to find workers who will take production supervisor positions. The supervisor stated: "It's almost impossible to get a supervisor now. They say, '"I wouldn't take the crap you guys take.'"

The automation in the body shop has made it much more difficult for the first-line supervisor to check the quality of the work produced. One production foreman explained that before automation, a supervisor could simply stand a little down the line from each work station and check the work of the people at the station. Now, the production foreman continued,

> ...you don't really have the opportunity to check quality. You don't really have a chance to look at your guys. You really don't know what the hell you're building. The supervisor gets frustrated out here a lot more. Because of the automation, you can't really look at the parts going around 40 feet off the ground (in the overhead conveyor).

Because it is hard for supervisors to check quality, and because the workers "don't keep their eyes on things," the superintendent said, "You can get 30 bad jobs before anyone notices." Like welder repair supervisors, production supervisors must remain alert to identify problems before a large number of bad parts are made or equipment gets damaged.

Automation has also increased the frequency with which workers must be shifted around; high downtime and greater coupling between different operations creates a need to move workers from one job to another periodically to avoid bottlenecks and to keep them usefully employed. According to the production superintendent, "You gotta juggle manpower. Pick up this weld, pick up that part. That's why these general foremen are so important."

Production supervisors share with welder repair foremen some of the pressure that results when equipment is damaged. To meet production goals, production foremen must keep the line going at all costs. The production superintendent emphasized this point:

> We had a meeting with one foreman last Friday. They get into the habit of holding the line a little. You can't hold the flaming line. A guy would say 'Blowhole (a weld in what will become the finish of the car), hold the line, I'll get this.' No way. Get it at the end of the line.

Production supervisors feel pressure to meet production goals most directly. If production is low or quality is poor, according to the superintendent, "People in other departments beat you over the head. Then you go up front (to plant management) and they beat you over the head. But that's the job."

Corporate management in Detroit has recently been trying to eliminate one man per week from each department, according to several managerial sources in the body shop; this adds more pressure to the job.[17] Only the body shop failed to lay off a production worker the week before the research team's visit. This pressure to meet production goals and reduce manpower is a result of the present competitive nature of the auto industry, not of automation. Its effect on supervisors, however, is mediated by automation. In the automated body shop, supervisors feel production pressure acutely, while they battle a complicated, integrated production system. Furthermore, they do not expect upper management to try to alleviate this pressure--it is viewed as part of their job. The superintendent again:

> Can I run without this, without that, how do I pick up this operation. That's basically what we're paid for. Nobody comes down here. To the plant manager, this is the hinterlands. My boss came down here one day and said, "Forget this, I'm gettin' the hell out of here. Just keep me informed."

The production superintendent summed up his feelings regarding supervisors' jobs in the body shop by saying, "You gotta be a nut or it'll eat you up. I don't think there's any job in the world that has more stress than we do."

Welder Repairmen

Access to the Trade

The advent of robot welders has broadened the skills required of welder repairmen. A highly skilled welder repairman must be able to program and maintain robots, and understand programmable logic controllers (PLC's), as well as repair the more sophisticated conveyors and monotractors that feed parts to the robot welders. To some extent, welder repairmen have taken on responsibilities traditionally handled by basic tradesmen, especially machine repairmen, electricians, and toolmakers. Indeed, the corporate Director of Manufacturing Engineering regards welder repair as an important part of the company's move to increase productivity through combining classifications.

The introduction of robots and Robogate-type systems into the body shops of auto assembly plants has dramatically increased the demand for welder repairmen. As a result, it is very difficult to hire journeymen welder repairmen from the labor market: companies must outbid others for the services of journeymen or apprentice other workers with related experience. In the body shop, few of the 55 welder repairmen added since 1980 have been journeymen. Usually, workers with related experience have been hired as trainees from outside the plant. Most frequently trainees have worked before as electricians or have some electronics background. Based on the length and character of their previous experience, the company awards trainees some initial credit towards the 8 years required to make journeyman. "Temporary welder repairmen," who come from within the plant, are also sometimes hired. They are the first to be bumped back or laid off in the event of cutbacks.

Of the 55 body shop welder repairmen on the rolls today who were not welder repairmen at the company in 1980, approximately 45 have come from outside the company, according to a supervisor. About 10 have come from off the line within the plant. Of these 10, only 2 worked within the body shop before becoming temporary welder repairmen.

The company used to sponsor an apprenticeship program within the plant for which production workers were eligible if they did well enough on a written exam. The last body shop welder repairman to come out of the program began his apprenticeship in 1974.

The Welder Repairman's Job

The research team talked with three welder repairmen during the plant visit. The union skilled trades' steward for the body shop selected these men, one from each of the three areas with robots: Robogate, side aperture, and the ARS line. An additional welder repairman was interviewed by telephone for 1 hour.

All the welder repairmen agreed that their jobs have become much broader. A repairman who had recently shifted from the ARS line to side aperture said, "They want all-around welder repairmen. They want a welder repairman, they want a millwright, they want a toolmaker, they want a pipe fitter, they want you to do everything." The others agreed that the job had progressed since the "tip-jerking" days when welder repairmen primarily maintained the tips on hand-welding guns:

> (There's) more advanced technology, you're involved in more different areas. With basic guns, you get basic weld repair. With robots you get everything from electronics, to hydraulics, to computers.

The welder repairmen all enjoyed their jobs, partly as a result of its increasing sophistication. The first repairman said: "I don't think you'd find a man here who'd refuse to do this work. It's broad, everybody likes the job. They love it."

His colleague concurred: "I enjoy the work; it's a good job." A third repairman also agreed: "(The job's) easier now, more of a challenge, more interesting. Without that challenge, I'd be bored."

Opinions varied about the adequacy of the training they'd received. The company flew some welder repairmen to another factory for 2 week training courses during the retooling of the plant in 1980. Some additional training had been provided in 1 and 2 week classes, and during on-the-job instruction from supervisors. In the opinion of one of the repairmen interviewed, the firm trained the welder repairmen well: "I think the training has been pretty good. The only drawback in the training was that everyone was coming new to the system." A second repairman called the training "very helpful." The third repairman would have preferred more training: "I'd like to have had more training than I've had. All our training has been OJT (on-the-job training)."

The welder repairmen regarded their job as somewhat pressured, but not nearly as much as had their supervisors. One of them, when asked if there is more pressure now than before Robogate, said:

> I would say so. It depends upon the individual. I'm on my feet all day; I never sit down. I'm ambitious; I want to get in there and learn it. So I guess there's a little more stress. It's a very interesting field. I hope they continue to improve the technology.

The repairmen noted the integrated nature of the new technology, but did not seem particularly concerned by it: "It's not as if it's gonna put the whole plant down (when there's a breakdown), but it cripples the body shop. We go down for 5 minutes and everybody's there."

One repairman did feel that some of the pressure on supervisors is passed down to them:

> Quite a bit (is passed down). What would you call it, harassment, agitation, irritation. My opinion is if a guy is doing his best and he's not reading (on the job), you leave him alone. If you go up to him and start nitpicking, his morale's gonna go down. Then you start to dislike your job, dislike your supervisor.

Both repairmen and supervisors emphasized the importance of the union in relieving hourly maintenance workers from management pressure. A repairman who had previously been a foreman particularly emphasized that union protection prevents those at his level from being subjected to the same verbal harassment as supervisors.

Welder repairmen did not seem to be particularly concerned about the turnover of first-level supervisors. They believed that the pressure they felt from supervisors did not come directly from those individuals:

> They (the first line supervisors) pretty much got their hands tied as far as that goes. We got some people who came in at the upper echelon, who came in with some ideas--they got everyone mad. I have yet to have an immediate boss that I've had any trouble with.

One repairman believed that management unwillingness to cede authority to hourly workers and lower level supervisors means repair work must be done "clandestinely:"

> ...The only pressure I feel is the frustration of not being able to treat the system right. We have to use some unorthodox methods to get around them...My specialty is the ARS system. They had a pretty bad problem there--the big awkward automatic tools. I designed a special hanger--brackets that hold the weld gun to the robot. I couldn't sell the idea to them. So we ordered spare parts for the four major pieces. Gradually I changed all the tools in that manner...We only lose about half as many hand-gear trains.

The welder repairmen believed the lack of preventive maintenance to be a big reason for much of the downtime at the plant. One repairman said, "I think the mechanical system's impeccable. The problem is the lack of preventive maintenance."

Although the introduction of automation has somewhat increased the skill gap between production and maintenance workers, the repairmen claimed no friction existed between them, personally, and the workers on the main and subassembly lines. They did admit, however, that tension does exist between some members of the two groups. One man remarked:

> (There isn't any friction) with me. I have seen cases where people have had trouble. where someone didn't want to listen to production people. The people in production have a lot of valuable things to say that are worth listening to.

His colleague admitted, "As far as production, they might resent it, looking over at a welder repairman sitting down because his robots are working."

Production Workers

The production workers interviewed at the auto company came predominantly from two areas: 11 came from side aperture, the subassembly area containing robots; 5 worked on the tabbing portion of the Robogate line.

While the hourly maintenance workers interviewed perceive the automation in the body shop favorably, the production workers, without exception, view it unfavorably. All of the 19 production workers spoken with believed that both their work and the atmosphere in the body shop have become more pressured since 1980. Since this time period coincides with the company's recovery from bankruptcy, it is impossible to separate fully the pressure associated with the firm's financial condition from problems related to automation. The combined effects, however, have been dramatic. Several of the workers reported that, for the first time, they have begun dreading coming to work. One production worker in an area just off the tabbing line said:

> ...you get to the point that you push, push, push yourself--you get up in the morning and the last place you want to go is that damn building, but you are going there because you know that you have to. I've never had that feeling before, never.

Subassembly Production Workers

In side aperture, workers perceived the automation to have increased the interdependence of jobs and taken from them the control they used to have over the pace of their work. Whereas previously subassembly workers could finish their work before the end of the day (or take long breaks) if they worked with sufficient intensity the rest of the time, they now complained of having to work throughout the day at a pace defined within narrow limits by the machines.

It is difficult to assess the extent to which this new interdependence is a result of the design of the system or management's current prohibition against banking. In some cases, management could break the link between the pace of separate subassembly work by allowing workers to "bank" parts between successive work stations. In other cases, however, there is little or no room for substantial banks. Moreover, the conception of subassembly operations as a series of sequential operations "paced" by a moving line arrived only with the automation of the body shop. Management's ultimate aim in subassembly, as indicated by the body shop superintendents' references to eliminating the "lakes" on the "river," appears to be the recreation of the rhythm and efficiency of the main assembly line. The automation introduced in the body shop is theoretically compatible with other forms of work organization. In practice, it is being used to turn subassembly into a simple extension of the main line. Side aperture is becoming a tributary of the main river in the plant.

A side aperture operator illustrated worker perceptions of the increased interdependence of subassembly operations:

> ...before you had more individual operations. Jim might work over there where he makes his little thing, and the other one might make his little thing, and everybody made their little thing and you might have maybe two people working together. Well, now you have maybe five, six, seven, eight...and everybody dependent on everybody.

Almost every subassembly worker interviewed complained about machine pacing which results from the interdependence of subassembly operations and the elimination of banks. Without banks, workers cannot earn breaks and control the intensity of their work. This conversation between a union committeeman and several side aperture production workers makes the point:

> Union committeeman: In piecework usually your incentive is that you'll get a bonus for making more than production. This kind of thing here in our plant, the incentive has always been what we call "ass time".
>
> First production worker: .. free time. A little bit of free time to yourself...
>
> Second production worker: ...and what has happened now is that they're...they've really eliminated the free time.
>
> First production worker: ...it's dependent on the machine.

Another worker described how the restricted number of hooks on the side aperture conveyor and gravity feeds makes it impossible to work far ahead: "There's only so many places, only so many hooks to hang them on and when those hooks are full you have to stop--do something else or take a break."

Workers emphasized that management forbids workers from building unofficial banks by their machines. "No metal on the floor" and "nothing on the floor but feet" are the catch-phrases of management in its recent drive towards eliminating the lakes on the river. One subassembly worker explained: "You can't build a bank now because there's nowhere to put it. You can't put finished metal on the floor." The union steward for the body shop elaborated:

> ...now we have no kind of metals on the floor. That hurts these guys (subassembly workers). Now if they could put something up for a little bank, it would be very, very good for these guys... they could basically get their time back.

A production worker added: "...at least you'd have something to look forward to...There's nothing to look forward to any more. There's no incentive, there's no nothing." Another side aperture production worker echoed these sentiments: "It was definitely better before because of the simple fact that we had a bank of our own."

Many subassembly workers referred to being paced by the machines. According to one, "It's not how much you put out, but how much it puts out. Because when it puts out, you put out."

Malfunctions of the automated framing operation exacerbate the tension resulting from being paced by the machines, according to the subassembly workers. Downtime mandates that the standard rate be set at 78 cars per hour (30 percent above the pre-Robogate level) to ensure that body shop output matches that of the rest of the plant. A subassembly worker talked about the disconcerting effect of unplanned stops for undetermined amounts of time: "So what you're doing is you're going and stopping, going and going, running and going. You know what that does to your insides? It changes your whole system."

Workers also objected to the fact that, because of high downtime, they don't know how many pieces they will produce in a day, how long the working day will be, or when their lunch will be taken. On the second day of the plant visit, a burst hydraulic pipe prompted management to call first shift lunch at 9:30 a.m. instead of 10 a.m. The afternoon session therefore increased from three hours 58 minutes to four hours 28 minutes. If extended breakdowns occur, the work day may be lengthened. If no problems occur, however, production may be met and workers sent home in 8 hours (and paid for 8), having met the daily goal. The committeeman compared this with the pre-Robogate arrangement:

> It used to be we'd be working an 8-hour schedule and they'd tell the man at subassembly, 'You build 424 (cars). OK?' Nowadays, they go over there and they're not sure how many they're going to build...they don't know exactly how long it's going to take. And at some point, they'll walk up to these guys and say, 'OK fellas, we're going to go 8.5.'

In addition to complaining about downtime and the elimination of banking, workers interviewed felt that the pressure from management has intensified since 1980. One subassembly worker stated:

> There was a time when you would go in there in the day and do your job and as long as you were doing your job the foreman never bothered you. Now they're always breathing down your neck for some reason or another. Always finding fault, something is wrong...It all amounts to one thing and that's pressure. The foreman is under pressure and he takes it out on you...

A second production worker spoke of discipline resulting from inability to keep pace:

> (to another worker) isn't there more of a problem with discipline these days, too...for inability to do the work, which is something that very rarely occurred before automation. You never got in trouble for not being able to do the work because you could do the work. But now, I think, you can learn a job easily enough but to physically be able to do it quickly enough. A lot of people just cannot do it, they just cannot do it. And people are being disciplined for that, and that is ridiculous.

To some extent, an increase in pressure might have been expected independent of automation simply because the company approached bankruptcy. Workers believed, however, that the atmosphere at work had deteriorated more severely in the body shop than elsewhere:

> ...it used to be sort of like a social life in here...it was like one big family. I have worked in other departments and I came back to body shop, because I liked the way it was back here better; but its not better now, I don't think.

When asked if the atmosphere had deteriorated in the other departments as much as in the body shop, the worker continued. "I wouldn't think so. I really wouldn't think so. I see a big difference in the body shop now than there was before."

To some extent, workers felt fear of unemployment has driven them to accept what they perceive to be an intensification of work. A side aperture worker commented:

> I'm going to tell you what our problem is basically, "Thank God I got a job." Work me to death if you want to, work me like a mule. At least I got a job. I ain't out there on the street like a whole bunch of turkeys.

Workers believed their fear of unemployment stemmed, in part, from the job loss associated with automation. The same worker continued:

> It has a lot to do with automation. When they brought this automation mess in here, we knew they were going to eliminate some jobs. But I don't think nobody expected it to be the way it was. Every other time when they've laid people off, people have come back. When they laid people off this time, we expected them to come back. But the more they told us to be grateful we got a job, the harder we worked...We're doing work now that they ought to be calling people back to work to help do some of that work that's in there.

The workers interviewed in the body shop were pessimistic about their chances of moving on to better positions. They believed that the welder-repair jobs created by automation were difficult to attain. Several workers mentioned that this results in resentment of the skilled tradesmen from outside the plant who do take these positions. One side aperture worker admitted, "People from outside come in. They put themselves above us. And that hurts us. The maintenance people on these machines, they aren't above making us feel that way."

Workers also believed that the number of preferred production jobs in the plant has gone down since 1980, making them difficult to get without long seniority. They viewed this as partly a consequence of layoffs. They also felt, however (and supervisors agreed), that the elimination of some better production jobs--repairman and quality inspector--

may have resulted directly from the improved dimensional consistency of automatically welded car bodies. Although down line quality problems often concern components installed well after the body shop, dimensional problems with the car frame that were common with the former system can lead to ill-fitting trim, fenders, bumpers, etc. While body shop supervisors could not be certain about the connection between the Robogate and the elimination of quality control and repair jobs, they believed the number of such jobs has diminished and that automatic welding contributed to the job loss. A production worker described the psychological affect this has on workers:

> There's another consequence to automation...As the guys were saying, the quality is better on the cars... so you don't need as many inspectors and you don't need as many repair people which are somewhat skilled trades...There's a department known as 9190 which is the final car conditioning area which we call "Autoworkers' Heaven," because you've got to have 20, 25, 30 years to get there. As far as we can tell, they're in the process of eliminating that department altogether. So not only are you humping away on that line--before at least you knew if you got enough time you'd get a fairly decent job. There are no decent jobs in that place anymore. You have nothing to look forward to. Just to die on that line...And at the rate they're making us work now, I mean, you're dying that much faster, much sooner.

Main Frame Line Workers

Production operators on the main frame line work on the tabbing line, in the roofing area, and in manual respot. Before Robogate, workers at the beginning of the main assembly line loaded parts onto gates and hand-welded them together. In the respot line, the gates dropped away and a combination of production workers and 13 robots applied strengthening respot welds. Workers and managers at the auto plant agree that on-line jobs maneuvering heavy hand-weld guns and gates and being showered with sparks were extremely unpleasant. In the words of one worker who is now in the subassembly area:

> All the spot welding jobs on the line--I remember when I welded floor pans. I had two big guns that I pushed around, and pulled and...what did I do after that?...I was in the pit welding side frame, and that was a rough job. I mean I caught hell doing it.

When asked, "Were you sorry to see those jobs taken over by robots?" the worker continued, "Well, those jobs, I think it was better that the robots took over."

Although the workers confirmed the commonly held belief that the hand welding jobs on the line were unpleasant and tiring, their opinion of the present jobs is no more favorable. Even more than for the subassembly workers, the automated machinery paces workers on the main framing line. When the Robogate stops, they must stop. When the Robogate speeds up to 78 cars per hour, they must produce at precisely that pace. A tabbing line worker said, "It's always breaking down...If I was broke down as much as they're broke down, I'd be fired."

Some workers believed their present jobs to be lighter because they need not handle heavy gates, but no more enjoyable. A worker on the tabbing line compared his past and present jobs in the following terms, "It's lighter, but faster...They want us to work like machines too. But we're not machines, we're people." His colleague gave a similar description:

> We aren't handling heavy gates anymore, but it's faster, much faster. They almost doubled my load. I'm working harder and longer than before. My job before wasn't easy, but you could do it in so much time...Now you don't have time to light a cigarette...I'd take my old job (hand welding on the line) any day.

He added later: "I didn't mind spot-welding. I enjoyed spot-welding better. The job wasn't that hard, wasn't that bad for me."

The amount of work on the manual respot line varies in intensity even more than it does on the Robogate line, depending on the state of repair of the robots in the line. If several robots break down simultaneously, workers may be doing several times more welding than usual: "When that robot misses (a weld) this guy got to take over for this bad boy for the rest of the day, or maybe another day, O.K.? And his job is basically not timed for that."

IX. THE IMPACT OF AUTOMATION ON SAFETY IN THE BODY SHOP

Although automation at the auto company has eliminated some dirty, unpleasant jobs, it has not created a uniformly cleaner, safer working environment for the workers who remain. While hazards associated with spot-welding have been eliminated, automated equipment has introduced a variety of unfamiliar safety hazards and resulted in a number of serious accidents. The welder repairman injury rate may have increased somewhat because these skilled tradesmen are now heavily involved in getting the line moving again if a problem emerges with a Robogate, a robot, or a conveyor. It is difficult to assess the relative injury rate for production workers before and after Robogate, although the company safety administrator and the union safety man believed it had stayed the same or improved slightly.[18]

Union officials, the company safety administrator, and body shop supervisors agree that the danger to welder repairmen is greater in the automated body shop than it was previously. Dangers stem from the complexity, unfamiliarity and automatic nature of the new equipment. For the first time, large numbers of automatic clamps, fixtures, carriers, and other components close and move constantly throughout the body shop. The production superintendent for the body shop explained: "Before you could get a nick, now you may get mangled."

The company safety administrator also said that automation endangers skilled tradesmen more than did traditional equipment:

> ...you've increased your skilled trades problem. In the old days, you had one gun, and you could shut it down and work on it. Now you got this complicated mess. If you don't know what you're doing, you could get hurt...We've had press injuries you didn't have before, and automatic clamps.

A welder repair general foreman also noted the occurrence of broken limbs: "We've (welder repair) had more injuries since Robogate than we had before, quite a few more. Broken toes, a broken ankle, falls." The foreman regarded hydraulic oil as one of the major problems in the automated shop. Unlike their predecessor, the hand-weld gun, automatic welding machines, press welders, and robots all use hydraulic oil to drive a motor or provide pressure. According to the foreman, "One of the greatest hazards is the difficulty of keeping hydraulic leaks down. It (hydraulic oil) doesn't evaporate. When you're climbing the machine, it's slippery."

Both the union safety representative and the company safety man said the number of injuries to production workers has decreased since 1980. They attributed this, in part, to the reduction in the number of workers in the shop. According to the company safety administrator, "It's improved (since 1980), but I can't say its a result of Robogate. The important thing is you have less people--that's definitely number one. Less people to get injured. Two, you have less equipment, and the equipment you use, you're less close to." Later in the same conversation, the administrator stated that, in and of itself, automation has made very little difference to the safety of the body shop. Rather, he suggested, "It (the level of safety) all depends on how much emphasis you place on safety." The union safety representative reported: "Established incidents are down from what they were. I don't think it's because of the machinery. It's because of fewer people. Fewer younger people."

Production workers themselves believe that safety is poor in the automated system, and probably worse than before 1980. Two problems, in particular, disturbed production workers. Like the welder repair general foreman, production workers expressed great concern about the pools of hydraulic oil that lie around much of the automated machinery. The-company safety administrator maintained, however, that the number of falls has not changed, despite the presence of hydraulic oil:

> There's more hydraulic oil now on the floor than they're used to be, but as far as the number of falls goes, it hasn't changed. Before you used to have weld water (which cooled hand-weld guns) on the floor.

Production workers also believe that lacerations and some more serious injuries have resulted from higher line speed in the body shop since 1980 and the pressure to make production quotas. Workers on the tabbing line regard the increased risk of cuts as one of the chief problems with the Robogate system. A tabbing line operator explained: "Before, the possibility of getting cut was remote. Now, it's easy to get cut. You can't come in with a hangover." A worker at the same station blamed the increase in line speed: "We work faster. It's easier to get cut." The union committeeman for the body shop suggested that the gravity feeds introduced in the automated system result in large numbers of lacerations because workers must lift large sheet metal parts onto hooks.

The union committeeman claimed that pressure to refill conveyors when part of subassembly suffers breakdowns leads to safety hazards:

> This (the need to catch up) is a real incentive for people to cut corners...to take chances. It's one of the reasons we do have a large number of lacerations. We had a terrible injury when a guy got his head caught in a press--they were bypassing the safety features.

The committeeman said that sometimes, rather than both workers pushing palm buttons at automatic welding machines, operators trying to make up production will override one of the buttons so one of them can start the next cycle a few seconds earlier. If the rhythm of the pair gets thrown, one worker may end up near the machine while the clamps close and welding begins. The company maintains that it strictly prohibits this practice and the practice is grounds for disciplinary action.

Although workers sometimes cut corners themselves, they seemed aggravated by a perception of management indifference to health issues. A side aperture worker pointing to a pool of hydraulic oil next to a machine believed management doesn't care about the risk of injury: "Somebody could slip and fall on this mess, but that's immaterial." Another worker talked of his failure to get a platform to cover the oil by his machine:

> I have a reservoir to stand in. I don't have a platform to walk on. My feet kill me constantly...I've already had one operation on my feet...For three and a half years I still can't get a platform...And I do this every day. I'll tell you if your feet get sore, it's rough. I've seen times I could hardly walk. But I have to be there the next day anyways.

X. COMPUTERIZED ATTENDANCE SYSTEM

One other application of computer technology that has had a significant influence on the work environment in the body shop is the computer attendance system. The "Uniform Attendance Procedure" was negotiated with the UAW on a national level and written into the 1982 contract as a joint labor-management program. The system establishes a uniform set of procedures for disciplining frequently absent workers. Each time a worker is late or absent, the foreman must fill out a standard form and check one of a number of excuse codes. The labor relations department enters the information on the sheets into a computer, which automatically alerts the department if a worker has been absent enough to mandate disciplining.

The procedure agreed upon in 1982 allows workers to take five excused or unexcused days in 6 months without any punishment. If they already have a total of five excused plus unexcused absences, and they have another unexcused absence, a foreman's report is filed and the worker must meet with the general foreman and union steward for the area. Labor relations provides a print-out of the worker's attendance record for the last 40 months. A further unexcused absence within 6 months results in a meeting of worker, superintendent, and union committeeman, and possible suspension for 5 days without pay. The next three unexcused absences result, respectively, in a 15-day suspension, a 30-day suspension, and discharge. Disciplinary procedures for chronically late workers have not been made uniform.

The uniform procedure culminates a gradual 3-year erosion of individual foremen's rights to discipline workers as they see fit. Over this period more and more information regarding workers' attendance and lateness records has been recorded in the labor relations computer. With time, it became common practice for foremen, when a worker missed a day, to call up labor relations to get workers' attendance print-outs, and to ask for a recommendation regarding discipline--a recommendation that foremen accepted with increasing frequency, according to the union committeeman. Even so, before the beginning of the new union/management attendance program in February 1983, different plants in the corporation had different disciplinary procedures and norms. Now the same procedure applies throughout the corporation.

In management's eyes, by making discipline more uniform, the procedure also makes it more just. A personnel administration supervisor explained that, in the past:

> ...two employees might be absent for the same reason on the same day. They might have the same attendance history. But one might have a good relationship with his foreman--maybe because they ride to work together--and so he is not disciplined. The Uniform Attendance Program eliminates that.

While it might have been possible to administer the present attendance system without computers, it would have required a sizable clerical staff. Furthermore, records of the past 40 months--including numbers of absences and late arrivals, and excuses given--would not have been so easily accessible. Therefore, it seems fair to characterize the reactions of supervisors and workers to the new procedure as, in part, effects of programmable automation on the work environment.

Supervisors' Reactions

Supervisors' reactions to the computerized attendance system varied widely. They did not generally believe the system has yet had much influence on absenteeism rates, or dramatically altered their relations with hourly workers. Some supervisors liked the system because it relieves them of responsibility for personally disciplining workers: hourly workers can be told that their supervisor's hands are tied. Other supervisors disliked this same characteristic because they can no longer reward good workers with time off (since excused and unexcused absences both count towards the five permitted days off) or use discipline more generally to motivate hourly personnel.

A general foreman suggested the attendance system can reduce pressure on supervisors because workers recognize supervisors applying punishment have no choice in the matter. The general foreman maintains:

> (The computer recording system) takes away from (the supervisor) the responsibility for disciplining people. It took away the need for the supervisor to have a confrontation... I think it does relieve the supervisor. For myself, I know it does.

The foreman described an incident that morning involving a man he had worked with for 22 years--"we were in toolmaking together." Because the uniform attendance procedure mandates particular punishments for each offense, the foreman said, he had no choice in disciplining his friend, and no dispute resulted.

Other supervisors did not like the inflexibility of the new system. One foreman complained about the lack of a distinction between excused and unexcused absences during the accumulation of the first five absences:

> The computer does not take into account certain relevant things that should be taken into account. Like if you give a guy a day off, he gets charged for that day. That's not fair. It's not fair to the supervisor and it's not fair to the worker.

Several supervisors noted that the attendance system has potential administrative advantages. For example, the foreman who complained of the system's inflexibility, added:

> The only advantage to me would be if you had a guy who was a chronic late problem or a chronic absentee problem, you can ask for a complete rundown on him: how often was he late, how late he was, what the excuses given were.

The production superintendent believed that the system has not been in effect long enough to be evaluated, although he suspected that it would not make much difference to some habitually late or absent workers or, in his words, the "pros."

Workers' Reactions

Workers interviewed strongly disliked the uniform attendance system. Production workers, in particular, expressed a visceral hostility to the system, blurting out "it stinks" or similar feelings upon its mention. The same workers sometimes acknowledged during the ensuing discussion that the company could legitimately complain about the high and growing levels of absenteeism. The overwhelming sentiment remained, however, that the system does not take into account various human factors that it should (fatigue, depression, family problems) and that computer recording and mandatory punishment prevent workers and foremen from developing the kind of give-and-take relationships they could in the past. A personnel administration supervisor expressed little surprise at the hostility of workers to the program, saying "where before you had a foreman who would be willing to forgive and forget, the computer won't forget."

A production employee who works to one side of the main framing line complained of the human factors left out by the computerized attendance system:

> With all these hours, if the fatigue factor enters, what do you do? You're going to miss time here, miss time there. Why? You're exhausted. Look right now at how we are going. We are working 9 hours a day and some instances you are going 10. You are working 6 days a week with one Saturday off and two Saturdays on. This unit (the computer) doesn't say to the company, "Is this man exhausted? Is this man tired? Does he have job problems? Does he have a family problem? Does he have any kind of a problem." It doesn't say anything there. The human factor is left out. The *human* factor is *out*. The fatigue factor is *out*. It is *cold* and it is *calculated*. That's all it is.

Another production worker interjected, "What they are trying to do is force you to come to work. You *have* to come to work or else." The first production worker then continued, "Did you ever hear of Big Brother?"

A union committeeman complained that the uniform procedure eliminates the possibility of negotiation when a worker is absent:

> One time, when they had discipline, we could bypass it most of the time. We could really negotiate. If Rodney or one of the guys got into trouble 2 years ago, instead of going boom, up to the computer, it would go into the office and, most of the time, we could get it settled...Before, a foreman could develop a relationship with his men.

Some workers acknowledged absenteeism to be a problem about which management has legitimate complaint. A side aperture worker admitted:

> ...it (the attendance system) upset me at first, but then I got to thinking, "Now, if I was in business for myself and I had hired people to work for me, I would expect these people to be there every day." Granted, people get sick and people die. You know you have to take off and go to a funeral, and I can see excusing people, but you have to admit there is a lot of chronic absenteeism. It seems to be mostly with certain people...Really, you can't blame (the company) for wanting to try to improve on absenteeism because it costs them money when people take off.

The feelings expressed by welder repairmen towards the absenteeism system were less intense. One repairman believed management didn't recognize the effect of the length of the work week:

> The hours we're working, 10 hours a day, 6 days a week, somebody's gonna take some time off. We're not married to the plant. We have other interests in life.

The same repairman also regarded the uniform attendance procedure as an attempt by management to claim it has nothing to do with discipline:

> The whole thing's a farce so management can sit back and say "I have nothing to do with it." But it (the computer) knows nothing that management doesn't put into it...If they want to get rid of this guy, they can get rid of him. If they don't want to get rid of this guy, he can take all the absences he wants.

XI. OTHER STUDIES

Although little has been written on the impact of robots on the social environment of the workplace, two recent studies reach conclusions consistent with those reached here. Both were studies of the effects of robots on workers, based on surveys conducted before and after the introduction of robots.

The first study is an analysis of the introduction of 30 robots into a Volkswagen plant for various applications.[19] The German government has been funding research to increase industrial capacity and humanize the workplace, and this study is an attempt to evaluate the effects of robots on the latter goal.

Unlike the subject of the present investigation, Volkswagen, at the time of the German study, was in good financial condition. As in this case, robots were found to have eliminated some physically strenuous, repetitive jobs, and to have increased the challenge of some (though not all) maintenance jobs. Looking at the plant as a whole, however,

> The conclusion reached by (the) study is that we cannot speak of a thorough improvement of working conditions; on the contrary, there are even cases which are to be characterized as deterioration. This occurs, above all, in cases where the robots have assumed the task of handling the tools and left the workers with the task of handling the material, that is, feeding new material into the machine.

Although the robots clearly reduced the physical strain of a large number of jobs, they also reduced worker control over the pace of work:

> Especially conspicuous was that in many cases the factory control of the work rhythm was increased and the worker's freedom of movement was thereby further restricted. Thus the possibility for the worker to regulate his own work, to set a faster or slower pace, obviously within limits, was reduced.

As at the U.S. auto plant, worker fears of unemployment intensified after automation:

> Existing fears about the loss of (hourly worker) jobs were intensified, despite the high assurance to the contrary which exists in this automobile plant. The already existing fears of wage laborers who stand on the lowest step of the factory hierarchy received new impetus.

The second study, from the Sloan Management Review, examined the psychological reactions of workers to the introduction of one machine-loading robot into a factory.[20] The three operators who previously loaded the machines manually and are now responsible for operating the robot all found "that the use of the robot eliminated the prior heavy and fatiguing work." However, like the welder repair supervisors in the auto plant, the operators "experienced more stress and pressure." Two of the workers said:

> First worker: There is more stress now...We have more responsibility...They want the robot to run and we have to keep it going...That's hard because it's still relatively new.
>
> Second worker: It's nerve wracking...there are a lot of details... it's an expensive piece of equipment.

Three limitations of the Sloan Management Review study are its examination of a factory that introduced only one robot, its limited operator sample size, and the fact that its interviews took place only two and half months after installation of the robot.

XII. CONCLUSION

In 1980, in response to consumer demand for small cars, the auto company which is the subject of this study designed a new unit-body car. The design of the new car's body necessitated substantial retooling of the welding facilities in the factories designated to produce the car, including the assembly plant focused on here. In selecting machinery for its new welding facilities, the auto company opted for perhaps the most advanced frame welding technology available. the Robogate system. In a Robogate, a large fixture holds a car body in position while robots apply stabilizing welds to establish its dimensions. The Robogate combined a number of features that appealed to management: flexibility which would lower retooling costs before production of new models, consistently placed welds, fast throughput, and lower labor costs.

In management's view, the Robogate, respot robots, automatic welding machines, and computer controlled carriers installed in 1980 have fulfilled their expectations--labor productivity and quality have improved, while retooling costs have dropped considerably. The system has also eliminated a number of hazardous and undesirable jobs. For many production workers and supervisors who remain, however, there has been a significant deterioration in the work environment.

- An intensification of work and an erosion in the quality of life on the job for production workers in the body shop stems from the fact that subassembly jobs are now tied to a line, the subassembly and main frame lines are run faster, and downtime creates stop-and-go pacing outside the workers' control.
- the responsibility for operating and maintaining the complex, highly integrated production system places great stress on supervisors, especially repair supervisors.

Neither of these changes is a direct or necessary consequence of automation or the introduction of robots. Rather, they arise from the *design* of the new frame welding system, and the operating practice which guides its daily operation. Two aspects of the design are especially important: the arrangement of successive subassembly operations in series, and the restriction of space for storing parts between these operations. One operating practice, the decision to store even fewer parts between subassembly operations than space allows, complements the design decisions.

The minimization of banks through a combination of system design and managerial practice brings with it the advantages of "just-in-time" delivery, according to the company manufacturing engineering director: low inventory, the rapid discovery of subassembly quality problems further down the line, and reduction of damage due to moving parts in and out of banks. In addition, the director explained, by restricting banking and preventing workers from regulating their own work pace, the company can stop operators from rushing and thereby producing low quality parts. The company can also guarantee that production workers work consistently throughout the day. In sum, by minimizing subassembly banks management believes it can assure a steadier, higher quality, and more efficient production flow.

This type of production flow in subassembly, however, has had a negative influence on the jobs of some production workers. In the past, when each subassembly worker or group of workers made a part which would go directly onto the line or onto a side-gate, groups worked independently of one another. Furthermore, when management permitted workers to pile parts on the floor, hourly operators could regulate their own work pace. Often workers would choose to work intensely during the early hours of a shift and finish a considerable time before the end of it. Now, subassembly operators have to work to within 10 or 15 minutes of the close of a shift. By tying subassembly work to a rhythm over which the worker has no control, the automated system has eliminated the feature of off-line jobs that made them more attractive than line jobs.

The downtime endemic to the automated system has also negatively affected the quality of workers' jobs in both subassembly and on the line. Since the installation of Robogate, body shop downtime has risen from 5 percent to about 20 percent, according to operating management in the plant. This new figure is not unusual for a system of this complexity. The integrated, serial design of the automated framing shop makes the operation of each part of the subassembly and main frame lines interdependent. With the exception of minor problems, the lines can only operate if all the equipment in them works well. While this design rules throughout most of a traditional auto plant, the simplicity and reliability of the technology, and the availability of backup equipment, generally limit downtime to a few percent--as they did in the old body shop. With automated equipment, downtime has increased by a factor of four.

Workers in subassembly and on the line complained about two consequences of downtime: the stop-and-go work pace; and the higher line speed necessary to keep up with the rest of the plant. These factors contributed to a feeling among some line workers that their present jobs are less desirable than their old spot-welding line jobs.

High downtime and the integrated design of the system have also led to a significant increase in pressure on welder repair supervisors. High downtime implies a higher ratio of crisis management to routine maintenance than before 1980; and the integrated design of the system makes it critical that malfunctions be repaired quickly. Before Robogate, a damaged gate or broken weld gun could be pulled to one side and fixed at relative leisure. In the automated shop, problems with most of the equipment must be solved before the line can start moving again. The pressure on welder repairmen is intensified by the minimization of buffers between successive subassembly operations. It may be further intensified by the upcoming elimination of the 45,000 square foot buffer. At present, this buffer--when it works--restricts the repercussions of short breakdowns to one-third of the framing shop. Without it, the repercussions may spread more rapidly throughout the body shop and to the rest of the plant. On the other hand, the removal of the buffer will eliminate a number of major causes of downtime in the system, especially problems experienced lifting parts into and out of high-rise storage space.

There have been two important benefits resulting primarily from automation:

-- robots have eliminated a number of physically demanding hand-welding jobs which required operators to work in the midst of the sparks thrown off each time a weld is made.

-- automation has substantially increased the breadth, challenge, and interest of repair positions. Rather than simply "tip-jerking"--removing the tips of hand weld guns and replacing them--as they did before robots entered the welding facility, repairmen now maintain a wide range of electrical, hydraulic, and robotic equipment, and they program the robots. The welder repairmen interviewed find that this increase in responsibility considerably improves the quality of their jobs.

Prospects for the Work Environment

Although downtime in the body shop appears likely to remain high for the life of the system, automated welding operations installed in the near future may well overcome reliability problems. The experience of the plant studied suggests a number of possible characteristics of the work environment in a smoothly operating body shop.

Pressure on repair supervisors would very likely drop considerably in such a body shop: maintenance work would consist more of routine work--programming robots, giving them periodic "physicals," replacing photo-cells--than of resolving crises. The pressure on supervisors may nonetheless remain somewhat above traditional levels for two reasons: when breakdowns do occur they will remain more costly per minute than previously because of the integrated nature of the design, and the equipment itself is more expensive than before 1980.

The stop-and-go pace of line and subassembly work would disappear. On the other hand, the subassembly work pace would probably be tied more tightly than ever to that of the main line. From a production worker's point of view, subassembly jobs in such a factory would be identical to line jobs. While they might be no worse than present subassembly jobs because lower downtime would mean less stop-and-go pacing, they would be at best marginally improved. Even more than the erratic pace, workers in the body shop blamed the dictation of their work rhythm by machines for the deterioration in their work environment.

FOOTNOTES

1. H. Allan Hunt and Timothy L. Hunt, Robotics--Human Resource Implications for Michigan, (The W.E. Upjohn Institute for Employment Research, Michigan, 1982), p. 3.

2. The auto company's Annual Report 1972, p. 2, and 10K report, 1982, p. 5.

3. "How Crisis Changed the Auto Industry," American Machinist Special Report 755, June 1983, p. 102.

4. Ward's 1983 Automotive Yearbook, (Ward's Communications).

5. The auto company's 10K Report, 1982, p. 9.

6. Ward's 1983 Automotive Yearbook, (Ward's Communications).

7. These figures were obtained from the division of the UAW responsible for representing the workers of the auto company studied.

8. "New Car Sales Increased 21% in Early June," The Wall Street Journal, June 15, 1983, p. 60.

9. Quote from article by Bryan H. Berry, Iron Age, October 1, 1982, p. 33.

10. Ibid, p. 33.

11. The auto company's 10K Report, 1982, p. 30.

12. An additional 25 repairmen with experience using robots in another plant worked in the body shop for the first 4 months after Robogate installation. These workers gained experience for the later introduction of Robogate into their own plant, as well as helping to ease start-up problems at the plant.

13. The actual downtime figure depends on how it is calculated. The production superintendent and a production general supervisor explained that they aim to run each part of the body shop at about 78 cars per hour. Given the 8-hour and 14-minute running time in a 9-hour shift, about 640 cars would be produced in a complete shift with no downtime. Actual production in side aperture and Robogate generally varies between 500 and 530 per shift. The above procedure for calculating downtime counts time when side aperture or Robogate go down completely and fractions of the time when the pace falls below the desired 78 cars per hour (due, for example, to a problem not serious enough to halt production entirely).

14. This equipment includes 64 robots, 110 automatic welding machines, 62 carbon dioxide welders, 74 manual weld guns (only a few of these are used continuously), approximately 60 stud guns, the monotractors, the main frame line, and the Webb outside the buffer.

15. The supervisor who provided the figures cited calculated them by counting from a list of body shop supervisors since 1980. All the other supervisors spoken with, including the welder repair superintendent and a welder repair general foreman, gave figures of between 19 and 22 for the turnover of repair supervisors since the installation of Robogate. Of the 16 foremen who have turned over, 5 reportedly quit and left the company, 8 resigned, and 3 transferred. The general foreman resigned. One of the superintendents quit and one was demoted. Of the eight ARS/Robogate/side aperture foremen, 3 quit, 3 resigned, and 2 transferred.

16. When an hourly worker becomes a supervisor his seniority freezes at the level when the promotion takes place. As a result, some workers with moderate seniority are reluctant to accept because they may lose seniority relative to those who remain hourly workers. Should the newly promoted supervisor subsequently return to hourly ranks (due to resignation or demotion) the supervisor would be more vulnerable to layoff if cutbacks take place. Since the 22-year old already faced almost certain layoff in the event of cutbacks, he risked little by accepting the promotion to first-level supervisor.

17. Corporate management denies any such directive had been handed down.

18. Efforts to obtain records on safety in the body shop from the union and the company proved unsuccessful.

19. Werner Wobbe, "Social and Organizational Aspects of the Introduction of Robots into Industrial Production: Results of a Social-scientific Analysis of Robots in the Automobile Industry," Soziologisches Forschungsinstitut Gottingen (SOFI), Federal Republic of Germany, 1979.

20. Linda Argote, Paul S. Goodman, and David Schkade, "The Human Side of Robotics: How Workers React to a Robot," Sloan Management Review.

FINAL REPORT

Education and Training Case Study Series

Computerized Manufacturing Automation: Employment, Education, and the Workplace

prepared by

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Office of Technology Assessment
U.S. Congress
Washington, D.C.

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EXECUTIVE SUMMARY

This report draws together the findings of 14 case studies of programmable automation education and training programs operated by industries, educational institutions, and a union/management sponsored training organization. A number of programs are jointly operated by educational institutions and government and/or industry organizations.

Research Methodology

The case study project began in July 1982 and ended in June 1983. The initial objective of the research project was to identify and contact a selected sample of institutions, organizations, and agencies known to offer or having the potential to offer programs designed to prepare individuals for jobs in computer-automated factory environments. Approximately 300 individuals representing industry, educational institutions, government agencies, professional associations, training and/or education associations, technical societies, and community organizations were contacted in the first stage of the research. This was augmented by a literature search. A sample of 100 training or education programs was identified, from which 20 were chosen to be the subjects of 14 case studies.

In consultation with the OTA Automation Project staff, the following sampling criteria were established:

- Geographical Spread. Programs were chosen from all four quadrants of the country, with a concentration of four programs from the heavily industrialized areas of southwestern Michigan.
- Instructional Deliverers. The case studies include programs operated by primary schools, high schools, community colleges, universities and 4-year

colleges, a union/management operated training center, and industries that produce and/or use programmable automation equipment.

- Types of Programmable Automation Training. Programs chosen provide instruction in computer-aided drafting and design systems, robots, programmable controllers, computer numerical control machines, automated vision systems for factory inspection, automated materials handling systems, specialized semiconductor fabrication equipment, and CAD/CAM networking systems. In addition, university programs addressing the systems approach to computer-integrated manufacturing education, plus in-plant programs stressing the systems approach for managers, are included.

- Occupational Categories of Trainees. Programs covered in the case study series address the needs of current or potential personnel in the following occupational categories: machine operators; electrical, mechanical, and other maintenance personnel; welders; electrical and electronics technicians; robotics technicians; mechanical designers and detailers; printed circuit designers; electrical drafters and designers; numerical control programers; general purpose programers; integrated circuit designers; piping designers and drafters; manufacturing engineers; design engineers; systems engineers; research and development personnel; shop-floor supervisors; managers; and executives.

- Size of Institution or Organization. Companies included range from firms employing under 170 individuals to multinational corporations employing hundreds of thousands of people. In terms of the size of the organization served by a single training division, the largest is 42,000. The educational institutions range in size from 2,400 to 34,000.

- Funding Source. Both public and private institutions and organizations are covered. Major public funding sources include Federal, State, and local government organizations. The union/management sponsored training program is supported by regular contributions by union members and management subsidy.

- Industrial Sector. Programs covered addressed the following industrial sectors: transportation equipment (including auto and commercial aircraft); electrical and electronic devices and machinery; nonelectrical machinery; and programmable equipment producers. Attempts were also made to identify successful programs in the metalworking industry.

Additionally, some programs were chosen because they evidenced cooperation among educational institutions, industries, and (in one instance) State and local government agencies. Two questionnaires -- one for companies and one for educational institutions -- were designed for use during on-site interviews (lasting 2 to 5 days apiece) conducted for each case study. The interview questionnaires are appended to this report.

Overview

This report is divided into three broad categories: industrial programs; programs in educational institutions (including joint programs with industry); and a summary of findings in which commonalities and differences among all of the programs are discussed. Both the industry and education sections describe:

- roles and functions of the programs, and the effect of programmable automation on traditional roles and functions,
- participation of other sectors in program delivery and/or design,
- needs, problems, and trends.

The concluding section includes a short summary of general roles and functions; a discussion of the present and potential capacities of the various types of institutions and organizations; and needs, problems, and trends common to both educational and industrial programs.

I. INDUSTRY AND UNION OPERATED TRAINING

The industry-based programs discussed in this section are divided into two major groupings: in-plant training delivered by company employees, and customer training delivered by the vendors of programmable equipment. Also included in the programs discussed under in-plant training is one union/ management-sponsored program operated by a Joint Apprenticeship Training Committee. In-plant training at six firms was investigated. The firms range in size from 280 employees to 42,000 (this refers to the size of the organization served by a single training division; in terms of total employment, the largest corporation visited numbers its employees in the hundreds of thousands). They are engaged in the manufacture of such products as transportation equipment, electrical and electronic devices and machinery, and machine tools. In-plant training delivered by two of the firms also discussed as *vendors* of programmable automation is included in the in-plant training grouping. Five vendors of programmable equipment are the focus of the customer-training section. The vendor firms range in size from under 170 employees to over 10,000 and produce hardware and/or software for such programmable automation as computer-aided design and drafting systems, robots, vision systems, machine controls, computer-numerical control (CNC) machines, and specialized automation equipment used in the semiconductor industry

IN-PLANT TRAINING

Although it is the object of this report to examine and categorize various education and training programs by type, it should be noted at the outset that the organizations or institutions that make up each group are characterized as much by differences as by similarities. The companies conducting in-plant training, for example, differ in the type of product manufactured and the type of manufacturing process utilized (for example, some use mass production techniques; others use batch production techniques; while yet others, like semiconductor producers, use techniques which are closer to the process manufacturing used by oil and chemical firms). Other differences that may directly or indirectly affect the type of programmable automation employed and/or the mode or content of training delivery are, e.g., whether or not the firm is unionized,[4] the size of the company (especially, the size of the unit -- entire company, division, plant, or department -- served by a training organization), the age of the company and its management philosophy, the market conditions for its products, the firm's philosophy of training, and the way in which the training philosophy is coordinated with the overall company operations and management goals. These factors will be included, when pertinent, in the following discussion.

In-plant training was examined at the following companies/plants: 1) a large aircraft manufacturer (which requested not to be identified by name) 2) Texas Instruments, 3) CADAM Inc., a subsidiary of the Lockheed Corporation and a producer of computer-aided design software, 4) Cincinnati Milacron, a vendor of robots, computer-aided machine tools, and machine controls, 5) a General Motors Corporation "S" Truck plant, 6) Westinghouse's Defense and Electronics Systems Center in Baltimore, Maryland. Also included is a programmable controller training program for journeymen belonging to an International Brotherhood of Electrical Workers (IBEW) Inside Construction Local. The latter program is a series of voluntary courses delivered by a union/management sponsored training organization called the Los Angeles Electrical Training Trust.

Roles and Functions

In the most general sense, the function served by all of the in-plant training programs[5] investigated is to provide job-specific training directly focused on the precise application needs of the plant. For the most part, in-plant training programs are made up of intensive, highly condensed and focused "short-courses" (usually 1-2 weeks in length) aimed at training individual workers to operate, maintain, or program computer-aided equipment or to use computer-aided design systems.

The union-operated program for electricians has a related, but slightly different function. While the union program is also job-specific, it defines "job" more broadly than the in-plant training programs and aims to give the individual union member proficiency at installing, maintaining, and programming automated equipment in order to increase his or her ability to perform as a journeyman electrician. The goal of the union-operated program, then, is to develop new skills specifically related to programmable automation to increase the body of general skills held by its membership and to keep those skills current with labor market requirements. Another difference between the union program and the in-plant programs is that the union program's intention is not to focus on specific company applications but, rather, to focus on providing broad general skills, giving its membership -- who may work for a variety of electrical contractors who install a variety of makes and models of programmable equipment -- familiarity with many of the major systems on the market. In other words, whereas the in-plant programs focus on increasing plant productivity and operating efficiency by increasing worker and equipment productivity, the union program focuses on strengthening an individual's skills and thereby strengthening the union's ability to respond to the needs of the management partners of the training program and the needs of the marketplace.[6]

Differences and Similarities Between Computer-Aided Design Training and Computer-Aided Manufacturing Training

While it is not fruitful to categorize differences and similarities in training programs according to each specific type of programmable automation equipment covered, there do seem to be some significant differences between computer-aided manufacturing (CAM) training[7] and computer-aided design (CAD) training. In the training programs investigated, CAM training focuses on providing the workers with the skills and knowledge required to keep the equipment operating at peak efficiency. In the case of CAM operations and maintenance, trainees often learn new manual and intellectual skills which must be added to their existing skills. For example, electrical maintenance personnel must learn computer programming in order to effectively maintain and troubleshoot the equipment; and operators of CNC machines, for instance, must learn to interact with the control panel and to monitor the machines rather than constantly interact with, or control, the machine itself in manual fashion. Thus, even though many in-plant training programs maintain the traditional distinction between the responsibilities of electrical and mechanical tradespeople and machine operators, all of the workers in these categories are cross-trained to the extent that they add familiarity with computer programming, or program loading or editing, to their original trade skills. In some instances -- in a number of electronics and semiconductor firms, for example -- maintenance personnel receive cross-training in electrical and mechanical maintenance as well as the type of programming skills described above.[8]

CAD training, on the other hand, focuses on system "users" rather than on machine or system "operators." The distinction between a CAD system user and a CAM system operator is significant, especially in terms of the training required. While the CAD user requires similar depth of background skills in, for example, design, drafting, or detailing as the CAM operator does in machining or welding, the interaction with the machines or systems is fundamentally different. CAM operator training focuses on program loading and editing, monitoring, and occasionally adjusting the equipment or process. CNC machine operation, for example, may involve some manual intervention to "tweak" the part being machined to ensure precision machining. In contrast to the program loading and monitoring function of the CAM operator, the CAD user is trained to *interact* constantly with the system, often as much as 8 hours per day. While CAM training focuses on ensuring that the *machines* operate efficiently to aid plant productivity, CAD training focuses on making those who will interact with the system proficient and productive users. Advanced CAD training often focuses on intellectual and creative processes which can help the CAD user make the most productive use of the system to complete his or her specific job. While CAD trainees must have prerequisite manual drafting or design skills, CAD training itself stresses intellectual and creative components over manual skill components. While trainees learn to *perform* specific system functions -- as, for example, to insert a line of specific dimensions -- the manual aspect is minimal and involves only the use of a lightpen or keyboard.

Regardless of the type of programmable automation training involved, however, all of the in-plant training programs in the present study include significant amounts of "hands-on" training. Although CAD user training does not require a high degree of manual *dexterity*, users must become proficient in interacting with the system.[9] CAM operators, likewise, require hands-on training to become acquainted with new skill requirements, such as program-loading and editing, and to learn how to use the computer controls to monitor the system.

Company-Based Differences and Similarities in Training Program Roles and Functions

The function of all of the in-plant training programs investigated is job-specific, application-oriented training. Nevertheless, a number of differences exist in such factors as the integration (or nonintegration) of programmable automation training with other types of in-plant training, the specific roles and organizational affiliations of the employees who deliver and/or initiate training, and the overall training and management philosophies of the firms.

A number of the firms have central training departments charged with responding to the identified training needs of the operating divisions. Only one instance was found in which the training department conducts all of the programmable automation training -- and that is in the smallest company investigated (280 employees). Training in two of the companies visited is intentionally decentralized. The following examples illustrate the great variety in training program organization and in the roles played by various in-plant personnel.

- At the aircraft firm (Commercial Division), a centralized training section delivers the vast majority of the programmable automation training courses. Those are divided into two major groupings: 1) "CAM" maintenance training for electrical and mechanical maintenance personnel, and 2) "CAD/CAM" training for designers, drafters, detailers, and programers -- most of whom are employed in design, rather than manufacturing positions.[10] (CAM operations training is normally accomplished through vendor training and on-the-job training.) Training is initiated by managers in the operations division, who are also responsible for selecting the trainees. The Training Section's functions include 1) delivering established CAM maintenance and CAD/CAM training courses in response to the stated needs of the operating divisions, 2) developing new courses in response to stated needs, 3) assisting the operating divisions to identify training needs, 4) coordinating vendor training delivered to the operating divisions, 5) establishing and maintaining open lines of communication with the operating divisions, 6) delivering "off-hour" training, in which employees may take a variety of programmable automation training courses not specifically required for their current jobs, and 7) delivering maintenance training to customers (usually airline employees). Aside from the full-time instructors in the Training Section, a number of other Commercial Division employees are involved in some fashion in training program identification, coordination, or delivery. Training coordinators in all

Commercial Division organizations communicate training needs to the Training Section, and temporary or permanent "training pockets" exist in a number of internal organizations.[11] The firm has also formed a companywide CAD/CAM Integration Team made up of representatives from design and production organizations. The Integration Team includes a CAD/CAM Training Task Group (also made up of design and production representatives) charged with gathering information on existing CAD/CAM training programs, identifying new CAD/CAM training needs, defining overall CAD/CAM training requirements, and developing some of the new training courses. The Training Section will deliver the majority of the new courses. In addition to Commercial Aircraft Division employees, others involved in automation training include trainers from a separately organized Computer Services Division which delivers computer programming and data processing training,[12] and instructors from vendor firms, who deliver customer training on their specific systems.

o Texas Instruments (TI) has a corporate-level training department which aids in defining training needs and in coordinating in-plant training with corporate operating goals. The operating departments have final responsibility for defining their training needs, initiating training requests, and selecting the trainees. The training itself is delivered by a variety of full- and part-time trainers. A large number of courses are delivered by subject matter experts employed full-time as designers or engineers in operating departments. In addition, TI employs nationwide over 2,000 full-time trainers who deliver programming, computer language, computerized management system, and other training both in-plant and to customers. Each organization in each division plus each satellite plant outside the Dallas area has its own internal training department which coordinates training on the plant or department level by pinpointing subject matter experts to act as part-time trainers and using the full-time computer trainers. TI also has a Corporate Manufacturing Technology Center that develops new programmable automation applications geared to the needs of specific plants and maintains an instructional staff to train plant employees to operate, program, and maintain the new automation installed.

o CADAM Inc., a vendor of computer-aided design software, has a centralized training department responsible for both customer training and in-plant training. Since CADAM produces no hardware, in-plant training is confined to programming training for all new Software Division employees (program analysts, software developers, and programmers) and CAD terminal operations training for any employee whose job requires it.

o Cincinnati Milacron (CMI) has a corporate training department that performs such functions as operating entry-level training programs, coordinating startup training in new plants, and organizing specialized training at the request of division managers. Most internal computer-aided manufacturing training, however, is delivered by three customer training groups, all of whom report to the service and sales departments of their respective divisions -- Machine Tools, Industrial Robots, and Electronic Systems (machine controls) -- and whose major responsibility is to train customers and CMI field service representatives. Because the three customer training groups have developed specialized expertise in training on their specific systems, they also deliver machine-specific training to CMI shopfloor and engineering personnel. Although the three customer training organizations are essentially independent of each other, their activities are coordinated by the corporate training department. As in the other companies profiled, selection of trainees is the responsibility of the manager or supervisor in the operating department.

- In-plant training in the General Motors Corporation (GMC) is primarily the responsibility of individual plants. GMC's corporate-level Education and Training Department serves as a resource to the divisions and their plants by providing technical advice and training assistance. Like other GM plants, the "S" truck plant in Pontiac, MI, has a centralized Education and Training Department, but that department focuses primarily on managerial and supervisory training, plus plant-orientation training for new shopfloor workers. The plant's "New Technology Training Program" for maintenance personnel -- which includes a series of courses on robot- and programmable-controller-maintenance -- is located in the Maintenance Department and is delivered by maintenance supervisors who have become full- or part-time trainers. The Maintenance Department management is thus responsible for both trainee selection and training delivery.[13] The program was first established around the time "S" Truck production began in 1980. The Maintenance Department received assistance from the Corporate Education and Training Department, the GM Tech Center robotics staff, and the plant Education and Training Department. In addition, equipment vendors delivered customer training at their own customer training centers and in-plant at GM.

- Training at the Westinghouse Defense and Electronics System Center is highly decentralized, although the Center does have a Human Resources Program Department which coordinates the Center's training programs and aids in training needs assessment and needs identification. In addition, a new training staff has recently been formed to oversee the design and implementation of training for new systems developed at a nearby R&D facility. That group is working on a plantwide strategy for programmable automation training. There are training coordinators at various levels, but a significant amount of in-plant training is done by first-line supervisors, engineers, technicians, and shopfloor workers who have received formal training in instructional delivery. The Defense Center's long-term goal is for every department manager and most first-line supervisors to be trained in instructional delivery, so that managers and supervisors will function as part-time trainers for their own employees. A second long term goal is for all employees to either deliver or receive 3 hours of training a month.[14] The philosophy behind Westinghouse's decentralized training approach focuses on both behavioral and task-specific objectives and is founded on the notion that training programs that are "owned" and operated by the departments that use them can respond most quickly to changing operational needs of those departments. Programmable automation training courses for new systems are developed before the technology is implemented on the plant floor. Mass training programs, delivered by departmental supervisors, have been designed for computer-integrated systems such as a materials acquisition center manned by 250 employees. At the other extreme, small-group training programs have been developed for automation that affects only a few workers. In one small-group program in welding robot operations, eight

> welders were trained during the final stages of applications development and aided R&D personnel by giving them the benefit of their (the welders') shopfloor expertise.[15] This type of participative training is expected to become commonplace at the Defense Center.

The in-plant training programs highlighted above were chosen as case study subjects because they have achieved, to a greater or lesser extent, a degree of success. Nevertheless, as should be clear from the thumbnail sketches, they were all organized and approached differently. This indicates that there is no single "correct" model for successful in-plant training. If there is any general formula to be derived from these various examples, it is that there must be serious attention to the need for training and willingness to invest in ongoing classroom/laboratory training based on the identified needs of the workers responsible for operating and maintaining programmable equipment. Naturally, success will also depend on how well the training program responds to the plant environment for which it is designed and to changes in that environment. While the above statement may seem self-evident, it should be regarded in light of the results of a survey commissioned by OTA of industries that use and produce computer-aided equipment. The survey showed that only 22 percent of the firms contacted that utilized programmable automation sponsored or conducted training programs in the use of the new technology. The most commonly cited obstacle to implementing training was "inadequate benefits relative to costs." Representatives of all of the firms profiled above draw a direct correlation between provision of proficiency-based training and worker and plant productivity. Although training costs and other factors have prevented some of those firms from expanding their already established training to meet all of the programmable automation training needs of both the individual workers and the plants, all of those firms are committed to the continuance of in-plant training to support the installation and/or expansion of programmable automation. Vendor training, while it does provide the necessary function of familiarizing employees with general operations and maintenance requirements, is normally not designed to focus on specific customer applications. While many equipment vendors tend to be highly responsive to the needs of their customers, neither they nor the customers define the vendor's major role to be the provider of application-oriented training. Training for specific applications is considered by both the vendors and the customers contacted in this case study series to be the provenance of the customer plant.[16]

Effect of Programmable Automation Training on Traditional Roles and Functions

The perceived need for in-plant programmable automation training, and the delivery of such training, have had significant effects on traditional training roles and functions in many of the companies visited. The most sweeping effects are seen in the instances of GM and Westinghouse.

Major Effects: GMC and Westinghouse

Like many other GM plants, the "S" Truck plant had no formal mechanisms for delivering in-plant classroom/laboratory training to shopfloor workers prior to the installation of programmable equipment in 1980. The plant Education and Training Department, which had the traditional function of delivering plant orientation and supervisory/managerial courses, did not have the technical expertise to provide the type of machine-specific training required by skilled workers. The training that existed for shopfloor workers before 1980 was either informally delivered through on-the-job training (OJT) or by equipment vendors. The plant's "New Technology Training Program" not only established a permanent technical training group but also awoke plant management to the need for an in-plant training/applications laboratory containing equipment set aside for training purposes.[17] The training was established by, and continues to be delivered by, the plant Maintenance Department, and trainers are selected from Maintenance Department foremen and supervisors. The Maintenance Department, thus, has a new role -- that of defining and fulfilling its own training needs. The plant manager of education and training also sees a need to expand the role of his department to include the coordination of training delivered by the Maintenance Department and other departments that now conduct, or may in the future conduct, in-plant training of a technical nature.

The Westinghouse Defense Center has had automated "technology pockets" for a number of years. Now, however, the computer-aided management information systems networks the Center's CAD, CAM, Computer-Aided Inspection (CAI), and Computer-Aided Testing (CAT) systems. Since 1980, a number of new factory automation systems -- including an automated materials handling system, robot systems, and a number of new CNC and DNC (Direct Numerical Control) installations -- have been introduced to the plant floor. The computer-aided management system -- which is taking the Defense Center in the direction of the "paperless factory" -- and the new plant-floor automation systems created the need for training strategies that could quickly address the continually changing needs of shopfloor workers and that would be applicable to both mass-training (when hundreds of workers would be affected) and small-group training. Eventually, training for new technology introduced to the plant floor will be based on a single approach, designed to be flexible enough to be adapted to the varying requirements of all affected workers. In the pilot program to train 250 workers for a newly opened computerized materials acquisition center, the new approach modified the traditional roles of engineers, supervisors, and shopfloor workers. The approach was to take the technical documentation for the system (written by Westinghouse engineers, who developed their own applications software and peripheral hardware for vendor-supplied automation systems) and to use that as a basis for users' manuals and lesson plans for the shopfloor workers who will operate the systems. The new method of training delivery turns the applications engineers into "master trainers" and the supervisors into part-time trainers of their own employees. In essence, the training process follows the path of the technology itself from applications lab to plant floor operation and employs as trainers those who developed the system (the engineers) and those who manage it (the supervisors).

Shopfloor-Worker Training Linked to Research and Development

Both the Westinghouse Defense Center and Texas Instruments have established manufacturing technology centers which link applications research to the training of the shopfloor managers and workers who will utilize the technology once it is installed. At Westinghouse, the applications engineers themselves are responsible for delivering training on the systems they have developed. The Texas Instruments Manufacturing Technology Center maintains a staff of trainers who are responsible for transferring the understanding of the technology to operational departments. While Texas Instruments engineers at the plant level focus on installing automated systems that require a minimum of development time and can be immediately absorbed into the production process, the Manufacturing Technology Center focuses on "strategic automation opportunities" -- long-range projects that may take a number of years to develop and test. The training associated with systems developed by the TI Technology Center is used to provide feedback to the development engineers and helps them to take into account worker response to 1) the technology, 2) the training, and 3) how the system fits into the plant environment. That feedback is then used in the final development stage, before the system is mass-produced and sent to other TI plants.

At both Westinghouse and TI, trainee involvement during the applications-development stage helps the researchers by providing them with information about shopfloor-user needs and with opportunities to test and utilize manufacturing technology in a practical environment. It also helps the shopfl· · workers by 1) allowing them to become familiar with the technology well before it becomes a permanent part of the manufacturing process and 2) enabling them to express their needs, concerns, and dissatisfactions well before the system is set in concrete.[18]

Other Effects: Cincinnati Milacron, Aircraft Manufacturer, IBEW

Other effects of programmable automation on traditional roles and functions are less profound, yet significant. The training of Cincinnati Milacron shopfloor workers by CMI customer training groups has removed some in-plant training functions from the corporate training department, which traditionally delivered all formal in-plant training. The corporate training department still maintains oversight responsibility for such training, but it is clear that CMI is moving in the direction of increased specialization of training functions (see p. 35 for another related trend at CMI).

In the aircraft company, trainers have been delivering technical skills training -- including programmable automation maintenance training, APT training, and other forms of automation instruction -- for a number of years. Those trainers do not perceive dramatic changes resulting from the expansion of computer-aided manufacturing technology. To them, the introduction of new technology is part of a continuing process involving not sweeping changes, but incremental additions to the responsibilities of the Training Section. However, the transfer of over 30 computer-aided design courses developed by the firm's Central Engineering Department has had a significant impact on the overall role of the Training Section. Until 1979, when it began delivering computer-aided design courses, the major function of the Training Section was to serve the company's manufacturing organizations. Now, the Training Section has five trainers who devote full-time efforts to training designers, drafters, and detailers in the various engineering organizations. The need for CAD/CAM training for design engineers in the late 1970's also resulted in a temporary role change for a number of engineers in the Central Engineering Department. Since the Training Section did not, at the time, have the expertise to deliver computer-aided design and analysis training programs needed by engineering personnel, the engineers themselves developed formal training courses and delivered them to their peers. (In the area of interactive graphics, this was done with the aid of vendor trainers, who worked with the aircraft company engineers to design and teach a series of CAD courses.) Another temporary training function is currently being carried out by the Training Task Group of the company's CAD/CAM Integration Team. The representatives in the Training Task Group are now identifying training requirements, assessing training needs, and creating an implementation plan which will result in new training courses.

The need to deliver programmable automation training has also resulted in a functional change at the IBEW/NECA[19] training centers in Los Angeles (The Los Angeles Electrical Training Trust). Training Trust courses are delivered after working hours to IBEW Local 11 members who participate on a voluntary basis. Because the Trust was established to serve the needs of all members of the Local (who support the Trust monetarily by contributing a small portion of their earnings to the Trust account), it is a basic tenet of the Trust philosophy that no formal selection and evaluation procedures be applied to students. Training Trust staff members have found, however, that evaluation and selection procedures must be applied to advanced programmable automation courses to keep those students with a complete understanding of the basic and intermediate material from being held back by those who have taken the basic coursework but have not made a full transition from electricity to electronics theory. Students who do not pass the evaluation for admission to the advanced courses are encouraged to retake the basic coursework and are given individual assistance by the Training Trust staff. This procedure has only been applied to automation courses and is not expected to have an effect on the other training provided by the Trust.

VENDOR TRAINING

In terms of roles and functions of the training programs themselves and those who deliver and support them, the vendor group is more homogeneous than the companies making up the in-plant training group. There are, however, significant differences among the companies deriving from the nature of the equipment and/or software sold, the size and age of the firms, the philosophy of the company management, the years of customer training experience, and the market for the equipment.

The five companies profiled are 1) Computervision, a vendor of computer-aided design systems (both hardware and software), 2) CADAM Inc., a software-only vendor, most of whose computer-aided design software is sold to purchasers of IBM hardware, 3) Cincinnati Milacron, Inc., a producer of computer-controlled machine tools, robots, and other products, 4) GCA, a producer of specialized automated semiconducter equipment, and 5) Automatix, a vendor of custom designed robot- and vision-systems.[20] With the exception of Cincinnati Milacron (CMI) -- which was founded in the 1880's and began producing computer controlled machinery in the 1960's and 1970's -- the vendor firms are relatively young companies. GCA was established as a research firm in 1958 and became product-oriented in the early 1960's; Computervision was founded in 1969; Automatix was created in 1980; and CADAM was incorporated in 1982.[21]

Roles and Functions

All of the training departments, with the exception of CADAM's, report either to the Customer Service Divisions or Customer Service-and-Sales Divisions of their respective companies. CADAM, since it does not sell hardware, has less of a need for a separate service division than the other firms. CADAM is also differentiated from the other firms in that training there is a major division, rather than a department, and the director of training reports directly to the president of the firm. While CADAM may be slightly unusual as regards the reporting relationship of the Training Division and the specific commitment of the firm's executives to customer training as a top priority item on the corporate agenda, all of the vendor firms visited demonstrated a strong commitment to customer training as a necessary part of product service and support. Although the systems, software, or machines sold by the five vendors perform a wide variety of functions, all of them are designed to increase the productivity, operating efficiency, and product quality in their customers' plants. The common goal of customer training is, therefore, to help the customers' employees understand and make effective use of the equipment. The computer-aided manufacturing equipment vendors -- CMI, GCA, and Automatix -- have the additional goal of training customer maintenance personnel to maintain the equipment properly and repair it quickly to reduce "downtime," which has an obvious impact on productivity.

Training as an Aspect of Product Support

All of the companies studied recognize that, if their customers' employees are not well trained, the customers may not experience the productivity gains they expect. In most instances, the training departments function as part of a larger support team designed to provide services deemed necessary to keep the systems and system users productive. Computervision, for example, has a hotline service manned 17 hours a day; a remote diagnostics center which can locate hardware faults that can be used by customers who have purchased a diagnostics aid (a modem that connects to the central processing unit at the customer's plant and allows long distance diagnostics over the telephone wires); a large field service staff; an applications support center that helps customers to locate software problems or operator errors over the telephone; applications engineers who visit the customers' plants to advise the customers on how to use the system most effectively for their specific applications; productivity specialists who conduct annual productivity reviews for specific applications chosen by the customers; and a media services department that provides audio-print training packages. Many of these services are training related. The applications engineers, for example, often deliver small-scale (one or two employees) informal training geared to the customer's specific applications; and the productivity specialists' reviews focus on the customer firms' training environment along with other factors and suggest ways to increase productivity through additional training, software or hardware enhancements, or changes of operating method.

Field service representatives at Automatix, GCA, and CMI also provide informal on-the-job training to customers. The Automatix training manager considers pre and postinstallation assistance provided by a variety of Automatix employees to be "informal training." This includes demonstrations and explanations of the system before installation by applications engineers; informal operations training by field service engineers when the systems are installed; on-the-job training by an applications engineer if a particularly complex system has been purchased; and further on-the-job training by field service personnel on how to deal with specific problems that may arise. The other vendor firms also provide some or all of these types of training related services to their customers.

Formal Customer Training Programs/Training Department Roles and Functions

In terms of formal training delivered to customers, the firms have courses ranging from 2-1/2 days to 3 weeks (depending on the complexity of the skills required or system covered) and all but one provide advanced (or "supplemental") as well as basic classes. The roles and functions of training department personnel vary from company to company and reflect individual characteristics of the companies themselves and the type of customers they serve. At Cincinnati Milacron, Automatix, and GCA, for example, the customer training groups are also charged with training the field service personnel. In most cases, the writing of training manuals and course curricula is also the responsibility of the training department or division, and a variety of approaches is taken in assigning curriculum writing responsibilities. CADAM, for example, employs a full-time staff of professional "instructional designers" with advanced degrees in curriculum design. Computervison's customer training department employs five individuals who spend half of their time working on curriculum design and the other half delivering training. GCA and Automatix trainers work on writing training materials as time allows.

The majority of the trainers have technical skills derived from shopfloor experience, from technical degree programs in colleges and universities, or from military training. Some were previously vocational education teachers or field service personnel. Four of the companies assign one trainer to classes ranging in size from 3 to 12 students. The trainer, in these instances, is responsible for both the lecture and the laboratory sections of the course (usually evenly divided). Automatix, however, takes a team approach to customer training. The Automatix Training Department, established less than 2 years ago, is a two-man department. The training manager, a communications and education specialist with no prior technical training experience, "anchors" the training courses by providing an orientation and overview and by coordinating the teaching of the technical and hands-on portions of the course. The full-time trainer, with an associate's degree in engineering and experience as an electronics and hardware technician, teaches the basic operations and maintenance sections of the courses; and Automatix hardware and software applications specialists come in to teach portions of the training. This team-training approach, while well-suited to Automatix -- a small, flexible company specializing in customized systems -- and to the multidisciplinary nature of robotics, would not necessarily suit larger firms producing standardized (i.e., not custom designed or configured) systems.

Standardized and Customized Training

While the nature of the Automatix product means that the Training Department necessarily delivers a large number of customized training courses, the other vendor firms will also, in certain circumstances, design tailored training to suit specific customers' applications. In most cases, customized courses are delivered to customers who purchase a large volume of hardware or software, with the training requirements sometimes being written into the equipment purchase contract. The majority of the vendor firms have constructed modularized training programs -- each module covering a specific task, a specific area of knowledge or skills, or a particular subsystem of the machinery. This makes it easier and more cost effective to create specialized training courses by piecing together various modules or parts of courses, and, when necessary, adapting those modules or creating new modules to fit the customers' needs. All of the vendor firms' trainers deliver the majority of their courses at company training centers, but all will also travel to the customers' plants on request.

Selection of Trainees and Prerequisite Skills Required

Although all of the vendors publish informational brochures listing specific prerequisites for their courses, it is, ultimately, up to the customer to decide whether or not to follow the vendors' advice when selecting employees to attend the courses. The major prerequisite for the basic courses is, invariably, core trade skills: knowledge of drafting, detailing, or design for the CAD courses; knowledge of electrical or mechanical maintenance for CAM maintenance courses; machining skills for CNC operations and programming courses; and knowledge of the process (welding for example) that the robot will carry out in robotics operations and programming courses.

Occupational Groups Served

Aside from training the users, programers, and maintenance personnel who will work directly on the computer-aided systems, the majority of the vendors will also train the customers' own instructors, and some offer special short courses for the executives and/or managers of the customer firms. The two computer-aided design firms are especially insistent on encouraging managers and executives to attend specially designed training sessions that provide them with an overview of how the systems function in their own plants, requirements for managing the systems most effectively, and advice on how to integrate them into their overall operations. CADAM and Computervision also offer special "train-the-trainer" courses that focus on theories of education and training, presentation methods, and the specific content of computer-aided design instruction. CMI does not offer specialized courses for instructors. It does, however, make special provisions for customer trainers by allowing them to sit in on CMI courses two or three times. Also, CMI trainers often monitor courses as taught by their customers' instructors and provide advice and assistance.

Changing Roles and Functions

Since four of the five firms were either established as programmable automation vendors or moved into the field shortly after they were founded, the majority of the training departments were specifically created to provide programmable automation training. Only in the case of Cincinnati Milacron, which produced conventional machine tools for decades, can the question of the effect of automation on traditional roles and functions be addressed.

CMI: Machine-Specific Training Plus "The Systems Approach" for Managers

At CMI, the manufacture and sale of electronic controls and CNC machine tools created the need for training departments specializing in machine-specific, formalized customer training courses. As new systems were developed -- first, electronic machine control systems for numerical control machines, then sophisticated computer-numerical-control machines, and, finally, industrial robots in the late 1970's -- separate customer training departments were established to deal with the growing need for cadres of expert trainers with specialized technical knowledge and training skills. Now, although the trend toward specialization continues, CMI is also considering the need to provide "process-type training" for managers who will be responsible for the firm's "Variable Mission Manufacturing Systems" -- modular, computer-automated, flexible manufacturing systems capable of producing different parts and adapting automatically to different mixes of part types. Manufacturing supervisors may be trained in the overall operation of the system, while operators, programers, and maintenance personnel will still need highly specialized training focused on specific tasks. CMI is now working on ways to instruct both CMI and customer managers in the overall process requirements.

Modifications Related to Company Expansion and Product Growth

While the training departments in the other vendor companies have not experienced the degree of change undergone by Cincinnati Milacron, certain modifications of roles and functions take place as the companies grow in size and market share and as the equipment itself is updated and modified. Although CADAM Inc. has been in operation for less than two years, the CADAM software product has been in use since 1967 -- first at Lockheed and then, in 1975, as a commercial product sold by Lockheed to other users. When CADAM Inc. was incorporated, the new training director determined that both the product and the customers would be better supported by changing the traditional role of the CADAM trainers, many of whom had been delivering customer training on the CADAM system for Lockheed for many years. In order to make the training more cost effective and more consistent, he increased the number of students per class from four to eight, and hired a team of instructional designers to write course curricula that call for the trainers to act as "facilitators" of the training rather than as the focus of the information and independent creators of their own courses. A number of CADAM system courses are now centered on self-paced training manuals that take the students through the lessons in a highly structured, logical fashion. The trainer is there to introduce the students to the general concepts of system operation and to act as a resource when questions or problems arise. The new training manuals are also designed to be used by customer trainers and by company managers overseeing self-study programs.

Computervision, whose training department has grown from three full-time trainers in 1979 to 33 today -- also stresses to its instructors the importance of acting as resource people rather than as "experts." Both Computervision and CADAM base their training on formal instructional philosophies -- CADAM's is called "Instructional Design" (or

"Instructional Technology"), and Computervision uses the "Instructional Systems Approach." Both combine behavioral and adult learning theories with a systematic approach to instruction in the attempt to create a highly structured, yet flexible, learning environment.

The history of the GCA Training Department illustrates a continual process of responding to the customers' stated needs for formal training courses, especially for maintenance personnel, and for increased depth and sophistication of maintenance training. The customer training group was created in 1978 in response to customer requests for maintenance training on the then-new DSW Wafer Stepper System®, used in the manufacture of memory and logic circuits. Previously, operations training was delivered informally to the customer firms' technicians during their "applications visits" to GCA. The first customer training courses in maintenance and operations were similar in nature to the approach now used by Automatix -- a team-teaching approach that calls on a variety of vendor employees to deliver separate sections dealing with their specialties. As sales increased and customers requested more in-depth training, an independent staff of full-time trainers was developed to meet the need.

While Automatix is still small enough and flexible enough to use the team-teaching approach, the training manager already feels the need to hire more full-time trainers who are specialists in specific fields. Automatix plans on continuing to use a version of the team-teaching approach but is now moving toward the creation of a self-sufficient training department. The training manager is now looking for more trainers in order to reduce the need for calling on Automatix applications engineers to teach portions of the courses. Courses will still be taught by a team of Automatix employees, but the team will eventually be made up primarily of full-time trainers (many with technical specialties) plus the training manager himself (who will provide the generalist approach for the orientation session).

Customer Training Trends

The changing roles and functions of all the vendor training departments may indicate some trends in customer training:

- Highly specialized "machine- and task-specific" training, together with a corresponding trend to train managers and supervisors in the operation of the system as a whole and/or in systems integration (i.e., the systems approach).
- An attempt to discover a method of training that is both flexible and systematic and that can cover the maximum amount of material in the minimum amount of time.
- Continued responsiveness to customers' needs.

It should be noted here that the customer training groups, as a whole, seem more consistently responsive to their customers' needs than the in-plant training groups, taken as a whole, are to their employees' needs.[22] That is not to imply that in-plant training is necessarily unresponsive or that there are not a number of instances where every consideration is made of the employees' needs -- nor does it imply that the vendor groups succeed in meeting all their customers' requirements. The point is, rather, that the vendors as a group appear to place a premium on trainee satisfaction. The reason for this is obvious -- if the students in vendor courses are not well trained, the customers may not experience the gains in product quality, operating efficiency, and productivity they expect; if special training provisions are not made for large volume customers, those customers may go elsewhere. It therefore makes good business sense for vendors to invest time and money into making their training courses as effective as possible. This business necessity has resulted in CADAM's and Computervision's use of formal learning theories which are taught to in-plant instructors who take the "train-the-trainers" courses. These program models, or others like them, may, if they prove to be highly successful, become more widely used in industrial training. Cincinnati Milacron trainers are also considering adopting another kind of formal training strategy which they hope will provide them with increased flexibility in adapting their training to specific customer needs when necessary. They are now working on creating a performance-based training model, which involves detailed task analyses of the customers' operations and a one-to-one match between the workers' tasks and the goals of the training program. The major benefit ultimately derived from this attention to instructional methodology is not necessarily the use of one system over the other but, rather, the attention that is being paid to discovering and using effective methods.

PARTICIPATION OF OTHER SECTORS IN IN-PLANT AND VENDOR TRAINING

A large number of the companies in the case study series conduct joint research programs with universities; most provide tuition reimbursement for job-related coursework at universities and colleges; and some participate with schools on various levels in joint education or training programs.[23] This section, however, focuses only on the participation of representatives of other sectors than business in the training delivered by industrial trainers, either to internal employees or to customer employees.

Universities: Curriculum Design and Instructor Training

A number of firms, both vendors and users, hire graduate students and professors from universities to aid them in developing curricular materials. CADAM has contracted out curriculum design projects to students and faculty at the University of Southern California's (USC) Instructional Technology Department and has hired a number of the department's graduates as full-time instructional designers. Texas Instruments also makes use of USC's Instructional Technology Department, together with similar departments in other schools, for aid in curriculum design. Westinghouse follows a similar procedure and, in addition, sends engineers, supervisors, and shopfloor workers to in-plant "Train-the-Trainer" programs developed by the University of Maryland. The courses carry one graduate-level course credit at the University, and will be followed by six additional University developed courses on various aspects of industrial training -- from task analysis, to new technology training, to management skills training.

Computervision has contracted out the design and writing of one of the "Pocket Reference Guides" (quick reference guides for already trained users) to university faculty members and plans to continue to contract for such services. CADAM, which is planning to develop software packages and training courses in architectural design, intends to seek out a univesity graduate department that excels in architectural design and either contract for, or exchange software and training for, the school's assistance in developing the curriculum.

Military and Federal Government Participation

Participation by these sectors is, for the most part, less direct than that of the educational sector. There is, however, a significant effect on training in those firms with government or military contracts. Computervision, for example, is currently delivering customized training to the U.S. Navy. The Navy specified training requirements and worked with Computervision to devise a series of modified Computervision courses to suit the Navy's needs. One requirement of the Navy contract was that Computervision rewrite its operator and training manuals to make them more readable and more user-friendly. Computervision used that requirement as an opportunity to rewrite its commercial documentation as well, to make it more reflective of user needs and more understandable to the average user. The Westinghouse Defense Center, a government contractor, is required to train and certify the workers who produce or test products sold to the government. Technicians and other workers in Westinghouse's microelectronics fabrication area, for example, must continually perform at the level required by government certification standards. Their performance is therefore measured and plotted monthly. When it falls below the required minimum level, they are sent to "refresher" training courses. Texas Instruments also has certification based training for its employees who work on products contracted for by the government. It would appear, then, that government, and especially military, contracts for products, equipment, and services encourage the contracting firms to pay close attention to training requirements.

NEEDS, PROBLEMS, AND TRENDS

Some trends pertaining to programmable automation vendors have already been noted on pp. 38-39. This section covers other major trends, together with common needs and problems, related to programmable automation training in the industrial sector.

Needs

Formal Classroom/Laboratory Training Offered on a Continual Basis

Representatives from all of the companies visited expressed their belief that formal classroom/laboratory training is required to support extensive programmable automation utilization. The vendor profiles indicate that, as those companies grow in size and market share, formalized customer training mechanisms must be set up to provide effective training. While a small firm like Automatix can fill its customers' needs by assigning part-time training duties to nontrainers in the company, it is clear that a self-sustaining training department will soon be required. The user firms profiled

-- while they still make use of time honored on-the-job training methods -- have all responded to the need for formalized classroom training for workers who use, program, and maintain computer-aided equipment. According to one company representative, a trainee who learns entirely through on-the-job training is most likely to learn only those techniques used by his or her unofficial instructor; while OJT is invaluable _after_ formal training occurs, only well-developed, well-delivered formal training can provide assurance that all the appropriate information is covered. Other company representatives said that OJT, while still a good training method, takes too long and is too expensive (because the trainee takes longer to get up to speed and the trainer, usually a supervisor, must spend a significant portion of his or her time delivering instruction). Others add that, even if a plant has no plans to expand programmable automation utilization, ongoing in-plant training is necessary because of normal attrition: well trained workers have a tendency to be promoted and are also attractive to other firms; in addition, normal work force fluctuation often creates an as yet untrained stream of new workers.

Plantwide or Companywide Training Strategies

While some of the firms visited had extremely well developed training strategies to support operational goals and employee needs, others have not yet developed comprehensive training plans. Some are in the process of assessing needs and designing training strategies. Cost factors, insufficient need for a plantwide strategy, lack of top management understanding of the need for such a strategy, or lack of aggressive management support were cited as reasons for the lack of comprehensive planning where it does not exist. Those companies that have formulated and implemented such a strategy believe it to be crucial to their corporate goals of enhanced productivity, worker satisfaction, and quality assurance. Those firms believe that a long-term investment in training -- which may not be recouped within 1, 2 or even more years of operation -- is essential to ensure future productivity.

Core Trade Skills Training and Basic Skills Training

Many of the firms discovered, when they attempted to implement programmable automation training, that a number of workers needed refresher courses to reinforce their core trade skills. Since these skills form the necessary foundation for much programmable automation skills training, many of those firms have instituted refresher programs -- valuable in and of themselves and for laying the groundwork for programmable automation training. A few firms and the IBEW training center also offer refresher courses in basic mathematics skills. According to Texas Instruments representatives, the lack of highschool and college student interest in mathematics creates a problem for industrial trainers who must teach technical training courses dependent on mathematics skills (See pp. 90-91). One problem associated with this need for refresher courses is the reluctance of many workers to admit that their basic or core trade skills have become rusty.

Cross Training and Communication

Cross-training is especially necessary for maintenance personnel who maintain, troubleshoot, and repair programmable equipment with electronic, mechanical -- and sometimes pneumatic and hydraulic -- components. In a number of instances, primarily in union shops, maintenance personnel work in teams of specialists. Even in those situations, however, some cross training seems necessary to educate a mechanical specialist, for example, to recognize electrical or electronic faults in the system.

A related need noted by a number of company representatives and engineering educators is the growing necessity for cross-training of design and manufacturing engineers. Failure of design engineers in traditional manufacturing environments to take production requirements into account can create costly manufacturing problems. In an integrated factory where a single data-set is used for design and manufacture, it is even more of a necessity for designers to be knowledgeable about the manufacturing processes. Similarly, manufacturing engineers should be familiar with design procedures and techniques to better communicate manufacturing information to designers. A comment made by a representative of one of the companies studied is illustrative of the increased concern on the part of many firms for reestablishing the once close working relationships between those engaged in design and manufacturing activities that, over the years, have become separate functions: "The time has passed when engineering drawings could be 'tossed over the wall' to manufacturing with an order to build it," he says. "CAD/CAM, because it leads to both sides relying on a common data base, which requires a common understanding of its content, tends to remove that wall." A number of the firms studied are considering, or have already implemented, plans for organizational restructuring to make the most effective use of CAD/CAM technology. In some of those firms, manufacturing engineers, logisticians, and field engineers are all part of the design process from the early stages of design conceptualization.

A need related to cross-training is for clear channels of communication between trainers and the design and manufacturing departments to enable the trainers to have up-to-date knowledge of current processes and training needs.

Scheduling and Selection

Many vendor and user company representatives pointed out the benefits of 1) scheduling training well in advance of peak production periods, 2) training the most accomplished and productive workers first (to achieve better productivity gains and to enable the most highly skilled workers to assist other workers who are trained later), and 3) making sure that managers and executives receive familiarization training to aid them in understanding the system users' needs and problems. If training is not scheduled well before production periods, department managers under pressure to meet design or production deadlines are likely to assign their least accomplished workers to training courses. When this occurs, especially in CAD training, the productivity gains can be appreciably less than if the most accomplished workers are trained first.

Problems

Training Departments: Organizational Problems

A number of training departments have some or all of the following problems: insufficient budgets, overextended staffs; lack of equipment dedicated to training; little or no organizational influence. While some of the companies visited have made great strides in reducing these problems, others have yet to solve them. Sometimes these and similar problems are seen in small, recently established firms that do not have the resources to put into training, or in firms that are feeling the pinch of economic circumstances. In other instances, it may be that upper management does not recognize the full import of the need for training or does not have a realistic assessment of what training costs.

Buried Training Costs

This problem is closely related to the one mentioned above. Training costs are "buried" when training is delivered unofficially and/or when the training is charged to equipment or production budgets. The result, according to a number of trainers interviewed, is that top management is often unaware of the money that actually goes into training and is sometimes unwilling to accept a realistic training budget when it is presented.

Trainee Problems

While some trainees are resistant to learning how to operate or maintain programmable equipment, this is much less of a problem than media publicity on robots and other computer-aided equipment would lead one to expect. It is notable that both vendor and in-plant trainers -- all interviewed independently of each other -- consistently reported that only 2 to 5 percent of the trainees fail to learn the course material because of resistance to computers or inability to understand computer operations. On the other hand, a number of students do enter the courses with what trainers often refer to as "computer anxiety." This seems to be especially prevalent in computer-aided design courses, primarily because those students are facing a dramatic change in the way they will be doing the majority of their work (since CAD operators, especially detailers and drafters who previously relied on pencil and paper, often interact with their terminals on a constant basis). Robotics trainers feel that the large amount of publicity robots have received creates a special kind of anxiety in a number of new trainees. Many trainees at first view the robot as an antagonist which may eventually displace them. While this is a not unrealistic fear for many workers, trainers usually point out to the trainees that those employees who are sent to robotics classes have the least likelihood of being displaced. The most common anxiety expressed by CNC-operations trainees is fear of losing control of the machining process. According to trainers, a number of machinists trained in conventional manufacturing processes equate "control" with manual control. Part of the training in these courses focuses on teaching the trainees to use their knowledge of traditional machining operations to anticipate machine motions and functions, which will help them to monitor the computer controlled equipment. All of the trainers address these various forms of computer anxiety on the first day of class and notice that the problem has usually decreased by the second or third day. In-plant trainers have found that open communication between workers, supervisors, and management well before the systems are installed produces a more productive training environment.

Difficulty in Keeping up with Frequent Hardware and Software Updates or New Equipment Installation

This problem affects both in-plant and vendor trainers and, of course, the trainees themselves. The CAD vendor trainers must create new courses for major updates and new releases of software and, sometimes, for new operating requirements for newly released hardware. At the same time, they must contiue to provide training for customers who buy the older hardware and/or software. This puts a tremendous strain on trainers, especially when they are also responsible for writing new curricula as well as teaching. CAM vendor trainers have this difficulty with new hardware models or new subsystems, which are sold as enhancements to major systems. GCA's semiconductor manufacturing equipment, for example, has numerous optional subsystems, many of which require separate training courses. For companies like Automatix which specialize in custom applications, keeping up is even more of a problem. Those trainers have to deal with keeping up-to-date with new technical developments, delivering standardized training, plus delivering more customized training than most vendors.

Similar problems exist for internal trainers in companies and plants expanding or updating their programmable automation capacity. While those trainers may not have the vendor-trainer problem of dealing with all software updates (often done quarterly), their problem is compounded by having to adapt their training to the companies' specific application needs. This requires continual communication with company applications engineers and supervisors in operating and design departments.[24] For employees responsible for operating, programming, and using the equipment, updates and new installations can result in the need to attend new training courses a number of times a year. While this is not necessarily a problem for employees, it does require their recognition that programmable automation utilization results in the necessity for frequent skill updates and an acceptance of the need to meet continually changing skill requirements. According to all trainers and educators interviewed, "life-long learning" is now a requirement for all workers whose jobs are affected by programmable automation. (This is discussed in more detail in Section II. Educational Programs.)

Difficulty in Finding and Keeping Qualified Instructors

This problem is felt more keenly by the vendor training department managers interviewed than by the in-plant training managers. Often, the precise mix of skills required of trainers is difficult to find. GCA, for example, requires electronics, precision mechanics, a familiarity with photography, and communications skills. In other instances, potential instructors with the required technical skills often have more lucrative employment possibilities as technicians, designers, or in other technical positions. Once trained to deliver instruction on the vendor equipment, the trainers then become even more highly skilled and even more attractive to other firms.

Trends

Formal Classroom Training Delivered In-Plant

Since the user companies profiled in the case study series were selected precisely because they had implemented formal in-plant training, the existence of internal training mechanisms in those companies cannot be said to constitute a trend. However, a number of the vendor firms report that many of their customers have set up ongoing internal training, either formal or informal, for those employees who will be working with programmable automation.[25] This is particularly the case with computer-aided design customers, possibly because CAD systems -- particularly if they are based on mainframe or 32-bit-minicomputer central processing units -- have the potential to form the hub of an integrated CAD/CAM operation. Most user company representatives interviewed -- from both the user companies profiled in the case studies and customers of the producer firms -- said that vendor training, while necessary and useful, is too expensive and too difficult to schedule to completely satisfy their training needs.

Increased Attention to Formal Instructional Delivery Systems

The use of formal instructional delivery and curriculum development systems has already been noted as a possible trend in vendor training organizations. Some user firms have also developed such formalized approaches. The Westinghouse Defense Center, for example, consulted educational psychologists and curriculum development specialists before designing its own formal mechanism for course planning and delivery. Defense Center representatives say that the implementation of such a mechanism resulted from the recognition that massive amounts of training would be required on a continuous basis to enable employees to cope with new installations of programmable equipment and with changes and updates to those systems. Two other user firms interviewed (customers of the vendors studied) were implementing in-plant training designed on the performance-based training model.

Moving Training Closer to the Job Site

Three of the user firms -- Westinghouse, Texas Instruments, and the GM plant -- expressly designed their training programs so that the training itself is either coordinated by or actually delivered by operations or maintenance department managers or supervisors. In these three firms, many trainers report to the department managers rather than to a separately organized training department. Representatives from all three firms believe that when the department manager is also responsible for training delivery, that training is more likely to be responsive to the specific needs of the department and the employees.

Machine Related Changes in Job Requirements

The differences between CAD and CAM training discussed on pp. 16-18 points to another training related trend which is occasioning changes in the workplace when programmable automation is introduced. Designers, drafters, and detailers who at one time only interacted with pencil and paper are becoming heavily machinebound and receive industrial training to use the computer-aided design machines to improve their individual productivity. On the other hand, the shopfloor workers who once interacted closely with their machines are now trained to interact less with the machinery itself. CNC operators interact with the control panel on the console and monitor the equipment to make sure that the machines are operating at peak efficiency.

Lifelong Learning

The need for industrial organizations and the people who work in technical capacities to adapt constantly to changing technology through frequent skill updates was noted above as a possible problem (p. 50) and will be discussed in relation to educational programs in Section II. The responses of the trainers and trainees interviewed for the industrial case studies indicates their recognition that both individuals and companies see the need for lifelong learning as a trend that is significant now and will become even more important in the future.

II. EDUCATIONAL PROGRAMS

The primary school, high schools, colleges, and universities highlighted in this section have established programs that address the need for technical education that includes programmable automation -- either directly or, in some of the primary and high school programs, indirectly by building mathematics, computer science, or basic engineering skills as a foundation for later education. In some instances, the educational institutions studied were well prepared to establish programmable automation programs, and little or no modification of roles and functions traditional to those schools was required. In those cases, the already established mechanisms and approaches that enabled the school to establish such programs are described. Because of the difficulties experienced by other schools where few such mechanisms were in place; because a large number of the programs covered are cooperative programs involving schools, industries, and other organizations; and because the efforts sometimes resulted in a redefinition, expansion, or modification of traditional roles, functions, or approaches, the first portion of this section describes the major functions of each program individually and the roles played by the program's participants. Following the detailed description of individual program roles and functions, there is a summarized examination of 1) effects of programmable automation on traditional educational roles and functions (pp. 88-100), 2) participation of other sectors in educational programs (pp. 100-109), and 3) trends, needs, and problems common to some or all of the educational institutions studied (pp. 109-115).

ROLES AND FUNCTIONS

Primary School and High School Programs

One high school program serving a number of school districts in the Detroit area was studied in-depth. In addition, two other high school programs (one in Dallas and one in the Los Angeles area) plus a Dallas Independent School District program serving grades 4 to 8 were covered as subsections of larger case studies. The primary school program focuses on mathematics (a necessary basis for technical education in the later school years). The high school programs ranged from robotics and computer-aided drafting vocational education courses to a more generalized technology program in an Engineering/Science "magnet" high school.

Dallas Independent School District: Intermediate and Middle Schools

Project SEED (Special Elementary Education for the Disadvantaged) is a nonprofit organization that, for 20 years, has been teaching mathematics to minorities and to educationally and economically disadvantaged students to raise their self concepts and their confidence. The Dallas Independent School District (DISD), which has funded a 2-year Project SEED program in the district schools, had an additional goal in mind -- that of creating student interest in mathematics, which, it is hoped, will encourage the children to continue with math studies in high school and to take math based technical coursework in high school and college. While children as young as 9 and 10 are exposed to remarkably high-level mathematics (including logarithms, exponential equations, and beginning calculus), the immediate object is not to teach them that high-level math but to create a favorable image of the subject in their minds and to make them aware of their own abilities to learn a subject that is both abstract and concept oriented.[26]

While Dallas' Project SEED is not focused directly on programmable automation or even on computer skills, it is seen by local school and industry representatives as a foundation on which to build the education or training necessary for children who may eventually work with programmable automation and other forms of technology. Although funded by the school district and operated in district schools, Project SEED classes carry no grades or credit and are not taught by the district's regular teachers. The 45-minute-a-day classes are sandwiched into the school schedule and are taught in addition to regular math classes. The program is directed by Project SEED personnel, many of whom were hired locally. Classes are taught by full-time Project SEED teachers, a large number of industry personnel (primarily from Texas Instruments) who take time off work to teach the daily classes, university faculty, and DISD administrative personnel.

Project SEED's function, then, is to supplement the coursework taught in the schools. Since the full-time Project SEED staff and volunteer teachers supplement the regular school staff, the project does not place added burdens on teachers. Although the final results of Project SEED will not be seen for years, preliminary information from a few of the schools indicates that the project has not only captured the interest of students and their parents, but it may also be improving students' grades in regular mathematics courses. In addition, full-time DISD teachers have noticed an improvement in verbal and listening skills in those children participating in Project SEED. School representatives, encouraged by the first year's results, now believe that Project SEED may serve other functions as well. One Dallas grade school principal reports that a significant number of families that had sent their children to private schools have now enrolled them in public school because of the success of Project SEED. Some school officials are hopeful that this may become a trend and that Project SEED may become a major force in helping them to counteract "the middle class flight from the schools" that began after the school desegregation laws were passed.

High School Programs

Oakland County Intermediate School District: Robotics and Computer-Aided Drafting Programs. The Oakland County Intermediate School District in southwest Michigan is comprised of 28 constituent school districts. The Intermediate School District is a regional educational service agency whose role is to provide services that complement and enhance the functions of local school districts.[27] One of the primary functions of the Intermediate District is to serve as a "Career Education Planning District" for new vocational education programs and to coordinate vocational education in four area centers, which serve the district as a whole by complementing the vocational education provided at high schools that operate individual vocational programs and by providing vocational education to students from schools that have no such programs of their own.[28]

In the summer of 1982, one of the vocational education centers offered a special 4-week introductory robotics program for incoming juniors and seniors. The intensive 64-hour course was a demonstration program designed to test the feasibility of teaching robotics and other high technology courses in the centers regular school year and summer offerings. Short term functions of the summer program were to familiarize the students with the fundamentals of robotics, to help them make future career and educational decisions involving robotics or similar studies, and to increase their interest in and awareness of high technology in general. Other functions can best be seen by briefly examining the roles played by individual school employees and others in the delivery of the program. An Intermediate District vocational education curriculum specialist coordinated the curricular activities and assisted in the development of a set of instructional materials specifically geared to the secondary level. The principal of the vocational education center obtained the necessary equipment (two teaching robots plus an Apple computer for programming them). Since no single teacher in the district had the expertise to teach the entire course, a team of vocational education and science teachers was created to develop the curricular materials and to teach the course. In the planning and curriculum writing process, the group of teachers, administrators, and specialists sought advice from a number of automakers and other industry representatives, many of whom agreed to either teach portions of the course or arrange for field trips to their plants.

The major function of the summer program was to pave the way for ongoing robotics and computer-aided drafting instruction in a variety of vocational/occupational programs offered during the school year. The equipment purchased for the summer program is now being used in some of the area centers, and most of the members of the teaching-team are now teaching robotics courses (or segments of robotics in related courses) in their regular classes. A number of the industrial representatives who assisted with the summer program now serve on an informal robotics advisory committee to the Intermediate District and aid in ongoing developmental planning. The school year programs approach the teaching of robotics in a variety of ways: 1) instructors at one center teach a semester long course in robotics; 2) instructors in another center are using student built robots to teach basic robotics principles in fluid power and electronics courses; they are also considering making use of a team-teaching approach by either forming a program cluster of robotics related vocational programs or by trading classes for 1 or 2 weeks to provide students with interdisciplinary knowledge and practice, and 3) teachers in a third center are using one of the teaching robots from the summer course to teach electronics, welding, industrial design, and machineshop students the fundamentals of robotics as these relate to the students' core disciplines. In addition, on the strength of the summer program's success, computer-aided drafting courses were initiated in two of the centers sooner than was initially expected. Both the robotics and the CAD courses have also helped to raise teacher interest in learning how to teach computer programming to students in industrial and other vocational courses.

The centers, in general, serve a dual function: they provide entry level skills-training and education for those preparing for jobs; at the same time, however, the instructors encourage all of their students to continue their education once they graduate from high school and attempt to lay the foundation for further technical studies. The robotics and CAD courses or course segments now being taught stress familiarization with basic computer operations and programming, familiarization with robotics or CAD (including hands-on practice) and career opportunity awareness. While the programmable automation programs at the centers (ranging from 2 weeks to 1 semester) do not produce full-fledged robotics technicians or CAD operators, they do provide workbound students with a basic orientation and some basic skills -- both of which may help those students in the workplace and may encourage them to take advantage of industrial training or postsecondary education programs.

The Los Angeles County Regional Occupational Program (ROP): Computer-Assisted Drafting and Design. ROP, which is sponsoring a year long high school course in "Computer Assisted Drafting and Design" (CADDS), performs a role that is similar in some ways to that of the Oakland County Intermediate School District. ROP's major function is to establish occupational training programs that do not duplicate or supplant the program efforts of other local education agencies. ROP classes are offered in all the school districts in Los Angeles County and are sponsored jointly by the Office of the Los Angeles County Superintendent of Schools and the individual school districts.[29] The purpose is to provide vocational, technical, and occupational "preparation opportunities" to high school students, out-of-school youth, and adults residing in the participating districts.[30] While the vocational education programs at the Oakland centers are comprehensive 2-year (900 hour) course series delivered in the centers' classroom/laboratory environments, the majority of ROP courses last for one or two semesters and, whenever possible, combine classroom studies with worksite training or hold all of the training at the worksite.

The year long CADDS course administered by ROP and the Glendale Unified School District is a cooperative project initiated by the chairman of the Glendale Private Industry Council (PIC), who also sits on the Board of Trustees of the Glendale Unified School District and, in addition, is a section manager at the Jet Propulsion Laboratory (JPL).[31] JPL, the Glendale PIC, and Computervision all participated in the high school CADDS program, which provides 4 hours of classroom instruction per week in two Glendale city schools and 2 hours of laboratory practice each week at the Jet Propulsion Laboratory. The program was designed to fulfill the following functions: 1) to familiarize high school drafting students with computer-aided drafting and design, 2) to provide upgrade training for the two high school teachers to enable them to teach the classes and to serve as resources for other teachers in the district, and 3) to incorporate the course into the school system's ongoing curriculum.

The roles of the other educational and institutional participants were as follows: The Glendale Unified School District selected the instructors, who, in turn, developed and teach the courses; the Private Industry Council absorbed the cost of Computervision customer training for the two instructors; JPL aided in curriculum design, provided laboratory and on-the-job training to the instructors, and provided laboratory space and equipment for student laboratory sessions.

The original object of the program was to provide familiarization training to encourage the students to continue in design-engineering or related disciplines in postsecondary institutions. However, the program also teaches entry-level skills which could enable graduates to move directly into positions as CAD-lab assistants[32] and from there, perhaps, into CAD operator positions. In addition to the technical skills and knowledge, 20 hours of career awareness training is provided.

Engineering/Science Magnet High School (Dallas). The Engineering/Science Magnet High School is one of eight magnet schools in the DISD, which draw the most interested and accomplished students (measured by achievement, proficiency, and basic skills tests) to centrally located schools to participate in a "fast track" program for 3 hours each school day. Unlike the other two high school programs covered, the magnet high school program does not focus directly on programmable automation. Rather, its function is to provide students gifted in technical and scientific subject areas a solid core of basic science, computer science, and engineering skills and to encourage them to take technology-based courses in colleges and universities. All of the school's students take an "enriched science sequence" during their first year of studies, an important component of which is a computer literacy segment covering the history of computers, computer applications, basic programming, and elementary flowcharting. They are also required to take a course segment on engineering communication (which teaches basic engineering problem solving techniques and includes a project in which they solve a simple engineering problem and write up their results). Graphics (basic mechanical drawing and blueprint-reading) is another required course. All students take electronics and computer science during their second year. By their third year, students focus the majority of their coursework on either computer science or engineering. The use of the computer as a problem solving tool is not only encouraged, but expected of the students. The ratio of computers to students is better than 1:3 (the school has 28 computers available to its 68 students).

Some emphasis on programmable automation is expected to come about as a natural outgrowth of the school's focus on computer science and engineering and as the school is able to acquire equipment. The school currently offers an advanced graphics course in which students make use of graphics tablets, and the school will soon acquire plotters for student use. At present, all the courses are taught by regular DISD teachers. However, the school principal hopes, in the future, to bring industry expertise into the school by hiring professional engineers and scientists who have retired from industry to teach such topics as solid state electronics. In addition, the school hopes to bring in industrial high-tech trainers to teach on a part-time basis.

Although Dallas has had a magnet school program since 1976, the Science/Engineering School is less than a year old.[33] Based on achievements to date, local school and industry representatives believe that the school may also be functioning to 1) help the public school system retain (or regain) the brightest students, many of whom have traditionally gone to private schools, and 2) create a highly skilled and educated local workforce for engineering, computer science, and other technical positions in the numerous local electronics companies and other high technology firms.

Community College Programs

The three community colleges studied operate programs which, taken as a whole, present a variety of approaches and cover a range of programmable automation coursework. Henry Ford Community College (HFCC), in the Detroit area, offers an "Automation/Robotics Option" in its Electrical-Electronics 2-year degree program. Together with instruction in robotics, the option includes technician level education and training in programmable controllers and other computer-aided manufacturing equipment. HFCC also offers a number of special courses in programmable controllers for union apprentices and journeymen. The two other schools -- Eastfield Community College in the Dallas area and Glendale Community College (GCC) in Los Angeles County -- operate joint programs with industry (and, in the case of GCC, with local government organizations) covering various aspects of computer-aided design. The Eastfield program in printed wire board design is a cooperative work study program with Texas Instruments and entails a great deal of participation by and coordination with TI managers and supervisors. The program at Glendale Community College is, in essence, a short-term industrial training program operated by the college in conjunction with local industry and government groups. A major goal is to increase the college's educational capacity by retraining its teachers and enabling it to incorporate computer-aided design courses into its ongoing curriculum.

Like the majority of community colleges across the country, the three schools define their major roles as 1) the education of students to meet lower division requirements of universities or 4-year colleges, 2) the provision of one- and two-year career programs in technical and occupational fields, and 3) delivery of adult education and personal improvement courses on cultural, social, civic, or other topics. All of the colleges provide active placement and counseling services, and all have provisions for cooperative work study arrangements. Actual opportunities for students to participate in cooperative education programs are, however, dependent on the economic circumstances and traditional college-industry relationships in the three localities.

The Henry Ford and Eastfield programs are both 2-year associate degree programs, while the Glendale courses in mechanical and electrical computer-aided design are expected to become part of the schools' 2-year drafting-and-design degree program. The programmable automation instruction in each school is (or will soon be) offered as part of a technical/occupational career program whose major function is to prepare students for technician level jobs in industry. However, Henry Ford has established specific articulation processes with nearby universities to enable graduates of the Electrical-Electronics Technology program and other technology programs to apply their coursework toward a Bachelor of Science degree with nearly complete convertibility of credits. GCC's catalogue clearly states which of the courses in the technical/occupational associate degree programs are accepted by specific local universities and 4-year colleges. While the majority of Eastfield Electronics Design course credits transfer to 4-year schools, no specific articulation agreements have been established.

Automation/Robotics Option: Henry Ford Community College

Unlike the other colleges in this section, HFCC has been providing students in its Electrical-Electronics Technology (EET) program with instruction in programmable automation for the past 10 years. Located in a highly industrialized area and headed by an administrator with 20 years of industrial experience, primarly in automated machine manufacturing, the EET program has kept pace with advances in industrial technology to the extent that funding, equipment, and laboratory space have allowed. The EET program has been an interdisciplinary program since its inception and includes cross-training in mechanics, hydraulics, and pneumatics.

HFCC's location in the Detroit metropolitan area has influenced both the design and functions of the Electrical-Electronics Technology program in general and the Automation/Robotics Option in particular. The administrators and the instructurs have all had previous industrial experience and maintain continued industrial contacts; and the program itself has been designed to address occupational opportunities in the local electricity/electronics market. All students in the Electrical-Electronics Technology program begin with courses in basic electricity and electronics and proceed to courses grouped into three subfields that parallel the three broad groups of employment opportunities for electronics technicians: 1) computer circuitry and microprocessors, 2) circuit analysis and instrumentation, and 3) programmable control and industrial automation.

Although students choosing the third subfield had been studying robotics and other forms of programmable automation as part of their regular coursework, HFCC did not offer a formally identified "robotics" option until the Fall of 1982. The formal option was created in response to growing numbers of requests by potential students and educational institutions for information on robotics courses and programs, and only three course modifications or additions were required to meet the need for a formal option.[34] The option itself -- which was specifically designed to be an option rather than a separate degree program in order to give the graduates the broadest possible career opportunities upon graduation -- was also developed with the specific career opportunities available in the Detroit area in mind. Completing the option prepares graduates for technician level jobs in assembly, field service, research and development, plant service, and sales in robotics and other forms of programmable automation. Students are informed at the outset that the union structure in the Big Three auto plants makes it unlikely that they would obtain maintenance and repair jobs in the plants unless they are already union journeymen or advanced apprentices with appropriate job classifications. HFCC students without union credentials are therefore directed toward jobs with programmable equipment producers and in smaller, nonunionized, firms. They would, however, be eligible for work under the direction of engineers in the Big Three plants as salaried technicians responsible for designing controls or for testing logic systems. Students taking the option are also prepared for a wide variety of electronics technician positions outside the field of programmable automation, including jobs in electronics firms, office machine firms, and electrical power companies.

Automation/Robotics coursework, like coursework in other industrial technology programs at HFCC, stresses knowledge of fundamental theories and processes and practical, hands-on laboratory work that simulates, to the greatest extent possible, actual industrial conditions. All of the technical courses have a minimum of 50 percent hands-on laboratory practice. The instructors are responsible both for teaching the lecture portions and overseeing the laboratory portions of the courses. Informally, however, the instructors fill a variety of roles. Aside from spending a great deal of time providing extra assistance and counseling to the students, they also donate time to such activities as fabricating and reconditioning special laboratory equipment, working with industrial contacts to obtain new or used equipment and to keep current on new industrial practices, and visiting industrial sites between semesters.

Related Trade Instruction for Union Apprentices and Journeymen: HFCC

Henry Ford's Related Trade Instruction Division provides over 230 courses of instruction for approximately 3,500 apprentices and trainees from over 250 industrial plants. It is one of the largest publicly funded skilled trade training operations in the country,[35] and its major role is to provide classroom and laboratory instruction required in skilled trade and related occupations associated with the manufacturing industry.

Apprentices in the Industrial Electrician Program take courses in industrial electronic controls and programmable controllers. The Related Trade Division has also proposed a curriculum revitalization project to revise the fluid power curriculum to include robotics courses focused on mechanisms, automated lubricating systems, or electromechanics. In addition, the division also delivers updating programs for journeymen -- one of which, delivered to the Cadillac Motor Car Company, trains journeymen electricians in the fundamentals of electronics, microprocessors, and programmable controllers. HFCC was chosen by Ford and the UAW as the site of the original Targeted Vocational Retraining (TVR) pilot projects provided for under the 1982 collective bargaining agreement. Although the first two retraining programs operated by HFCC did not focus on programmable automation,[36] the director of the Related Trade Instruction Division plans to propose a project based on the Cadillac program to the Ford-UAW National Training Center as a future TVR project.[37] The specific functions carried out by the division are, therefore, 1) apprenticeship training (including programmable automation coursework in appropriate disciplines), 2) journeyman update training in programmable automation and other fields, and 3) retraining (a function which is expected to increase in importance).

Printed Wire Board Design Program: Eastfield Community College

Eastfield's Printed Wire Board Design program is, in essence, a program within a program: it is a modified version of the school's 3-year-old Electronic Design Degree Program specifically geared to the needs of Texas Instruments employees, who are sponsored through the program by the company.

Program Initiation and Design. Both the Electronics Design Degree Program and the Printed Wire Board Program were conceived by Texas Instruments representatives, who have traditionally had a great deal of difficulty in finding local Dallas residents to fill PWB design and other technical positions. TI's initial suggestion to Eastfield was that the school create a program option that would combine courses from the school's drafting and design curriculum and its digital electronics program. To make sure that the need expressed by TI was a general community need, Eastfield representatives 1) created a task force composed of industrial representatives and interested educators to explore the feasibility of the proposed curriculum, and 2) initiated a survey to document the need for electronic designers. Both the task force and the survey substantiated the need for the new category of designers, and the Electronics Design Degree was formally launched in 1979. While the degree program was open to all interested students, a special program within the degree program was created for Texas Instruments. During the program design and development stage, then, the roles played by the various participants were as follows: Texas Instruments conceived of both the degree program and the special program and proposed them to the college; sent a representative to the college task force; aided in curriculum design; and donated some equipment required for the new programs. Eastfield Community College set up the task force; initiated the survey; and designed the curriculum for the new degree program and the specialized TI program. The Dallas County Community College District Technical Occupations Office (which serves all of the colleges in the district by providing technical assistance and conducting occupational needs surveys and other types of research) conducted the survey; and other local industries, including Rockwell, Western Electric, and Mostech, sat on the task force, assisted in curriculum development, and some provided equipment.

PWB Program Roles and Functions: Texas Instruments and Eastfield. TI is responsible for recruiting and selecting high school graduates and current employees whom TI sponsors as program participants. All TI participants, including the recent high school graduates selected specifically to take the program, are on the company payroll from the first day of coursework. The program itself begins with one semester of full-time study at Eastfield. Participants then take three more semesters plus summer courses while also working 8-hour days in on-the-job training positions at TI. Apart from sponsoring the students financially and providing on-the-job training (which earns college credit as cooperative work-study experience), TI assumes the following roles: 1) monitoring and counseling of program participants on the job and in school (done by an appointed program coordinator); 2) providing regular pay increases to the students at the end of each semester, plus merit increases for those earning "A" and "B" grade averages; 3) giving special tutoring in difficult subject matter areas, and 4) on-the-job upgrade training at TI for Eastfield instructors teaching the PWB design courses. In addition, Texas Instruments encourages a number of its employees to work as part-time Eastfield instructors for some of the more advanced PWB coursework.

Eastfield's roles are 1) to provide the TI participants with separate course sections that, in some instances, include information specifically geared to TI work requirements;[38] 2) to assign administrators and instructors to serve as campus coordinators for the program and to visit the students during the cooperative work experience portions; 3) to provide weekly progress reports and copies of midterm and final grades to the TI coordinator; and 4) to assign mathematics tutors to those students in need of special assistance.

Mostech, a local firm, donated some old CAD equipment to the school, which was later replaced by a new Computervision system purchased by Eastfield (with the help of county and state funds) and a Redac Cadet system donated by the vendor. The new equipment has enabled the school to expand its CAD offerings: PWB and Electronics Design students now take both an "Introduction to Computer-Aided Design" course and an advanced course focusing on electrical schematics and printed circuit board design. (In addition, a mechanical computer-aided design course has now been developed for students in other programs.)

While the major function of the PWB course, then, is to provide Texas Instruments with designers educated and trained to the company's specifications, TI's interest in establishing the program and its help in implementing it has also resulted in the creation of a more generalized degree program that serves the needs of a broader segment of students and industries in the Dallas area. In addition, Eastfield was awakened to the need to obtain CAD equipment and offer computer-aided design courses as necessary segments of its various design curricula.

Computer-Aided Design: Glendale Community College (GCC)

The Glendale Community College program is, in part, an outgrowth of the Glendale High School CADDS program discussed on pp. 60-61, and the two programs share a number of similarities in relation to the roles and functions of some of the major participants. The direct impetus for the establishment of the GCC program was, however, provided by a "Coordinated Funding Project" conceived and administered by the Chancellor's Office of the California Community Colleges and the State's Employment Development Department (EDD). Funded by a combination of Federal and State monies and sponsored on the State level by the two State agencies mentioned above, the Glendale program is one of six pilot programs in California which bring together colleges, industries, and local government agencies to train California residents to work in emerging or expanding technological fields. The roles and functions of the various State and local project participants are discussed below.

State-Level Roles and Functions. The California State Legislature played a major role in the creation of the Coordinated Funding Project by setting up a legislative task group in 1979 to review vocational education in California and to suggest how vocational education funds be utilized most effectively. In its final report, the Task Group made the following recommendations: 1) the adoption of State-level administrative policies to allow for the consolidation of resources, 2) greater private sector involvement in vocational training, and 3) expansion of programs linking worksite training and classroom instruction.

The Coordinated Funding Project was established to respond to those recommendations by sponsoring innovative community college programs in emerging or expanding technologies or labor intensive occupations that combine classroom instruction with worksite training. Specific functions to be fulfilled by the local programs chosen to receive Coordinated Funding grants included: 1) the provision of vocational training programs meeting specific local employers' needs, 2) the involvement of local employers and other appropriate entities in project planning, curriculum design, and training implementation, 3) placement mechanisms for obtaining continuing employment with career advancement potential for project participants; and 4) incorporation of the resulting curriculum into ongoing college vocational education programs.

The Chancellor's Office and EDD representatives performed a significant function by consolidating State and Federal funds from three sources -- the Comprehensive Education and Training Act (CETA), the California Worksite Education and Training Act (CWETA), and the Vocational Education Act (VEA). In addition to initiating the project and coordinating the funding, Chancellor's Office and EDD representatives also sent out Requests for Proposals to all of the community colleges in California, selected the six project operators, and provided administrative support to the selected colleges. In the Fall of 1982, the Chancellor's Office and the EDD sponsored another state initiative, titled "Investment in People," to fund other college programs of a similar nature to those supported by the Coordinated Funding Program. Glendale submitted an Investment in People proposal containing a modified and expanded version of its original Coordinated Funding Program and was awarded additional funds to train other participants (including employed designers requiring upgrade training) in various computer-aided design applications.

Local-Level Roles and Functions. The Glendale program is a joint effort on behalf of Glendale Community College, the Jet Propulsion Laboratory, Singer Librascope (a divison of the Singer Company engaged in the production of military equipment), and the Glendale Private Industry Council. The 24 program participants -- who had previously been students, displaced workers, or underemployed workers -- received 12 weeks of formal instruction (6 hours a week of classroom instruction and 6 hours per week of Computervision terminal training at either JPL or Singer Librascope). Following the 12 weeks of formal instruction, they received 7 to 10 weeks of worksite training (at salaries of $5 per hour) at the participating firms. The program was divided into two sessions of 12 trainees apiece.

> Glendale Community College. GCC functioned as the official program operator and, as such, had fiscal responsibility for the project. It was also responsible for delivering the classroom and laboratory training and for appointing a program counselor to act as liaison between the students, the college, and the participating companies. The college's director of special projects for vocational education served as the overall program administrator. Administrative services were subcontracted to the Glendale Private Industry Council, while the college retained the functions of recruitment, screening, counseling, and placement. The college's senior drafting instructor was responsible for developing the curriculum, delivering the classroom instruction, overseeing the laboratory instruction, and coordinating with the two employers.
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> Industry Participants. The students were trained for mechanical computer-aided design positions at JPL and for printed circuit board detailer positions at Singer Librascope. The functions assumed by the two employers included the following: 1) assistance in program planning and curriculum development, 2) provision of on-the-job training for the Glendale instructor during the summer before the program commenced operation, 3) selection of program participants from a group of finalists prescreened by the college, 4) provision of space and equipment in the company laboratories for the hands-on training section of the course, plus informal assistance during the hands-on training, 5) 200 hours of worksite training for the program participants following the 12 weeks of formal classroom/laboratory instruction, and 6) hiring of selected program graduates.[39] Computervision participated in the program by delivering free training for the GCC instructor in its Los Angeles training center and by providing reduced price training manuals.
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> The Glendale Private Industry Council. The Glendale PIC (see footnote 31) played two roles. Its formal role was to provide administrative services for the program, including contract compliance, recordkeeping, participant tracking and reporting, operational monitoring, and technical assistance. These services were subcontracted to the PIC by the college. The other role played by the PIC was

informal but crucial to every aspect of the program from conception to delivery. The Glendale PIC defines one of its major roles to be that of a facilitator, or broker, that can act to bring together representatives from business, education, and government to create a working partnership between the sectors. It was acting in its role as facilitator that the PIC had its greatest impact on the Glendale College program. The proposal that won the Coordinated Funding Project contract for the college was conceived by the PIC director and was an adaptation of the Glendale High School program described earlier, which was proposed and initiated by the PIC chairman. It was also the PIC that secured the participation of Singer Librascope and Computervision.

The combination of classroom and worksite training in the Glendale program produced a number of beneficial results, not the least of which were the availability of state-of-the-art equipment at the industry sites and the opportunity given to the trainees to acclimate themselves to industrial environments. Since, however, GCC has no CAD equipment of its own, college representatives are aware of the possibly self-destructing nature of the project once JPL and Singer are saturated with trained employees. Three possibilities now exist for the continuance of the program and its incorporation into GCC's ongoing curriculum: 1) the college could find other industries willing to share their labs and equipment in exchange for trained workers, 2) the school could find a way to purchase or obtain its own equipment, or 3) the community of Glendale could set up a centrally located high technology training center, supported by local industries, schools, and agencies and outfitted with computer-aided equipment to address a variety of high tech skills. The latter possibility, one conceived of by the chairman of the Private Industry Council, now looks promising. It will be discussed in more detail on pp. 99-100.

University Programs

Three university level programs were studied in depth: Brigham Young University's Engineering Technology Programs; graduate and undergraduate engineering at the University of Michigan; and Worcester Polytechnic Institute's engineering programs. The major focus of the Worcester Polytechnic (WPI) case study is the school's Manufacturing

Engineering Applications Center (a joint industry-education endeavor involving robotics applications projects); the focus of the other two studies is on programmable automation studies in specific colleges and departments in the universities. In addition, a cooperative program between Texas A&M University and Texas Instruments was studied as part of a larger report focusing on Texas Instruments' relationships with a variety of educational institutions. That program, involving the school's upper division and graduate-level integrated circuit design courses, is also included in this section.

It is important to note that the differences in focus of the case study reports and the differences in size and goals of the universities covered makes direct comparison between the four unwise in most instances. The University of Michigan case study addresses the Engineering College (which has an enrollment of approximately 5,500 students) as a whole as well as programs operated by a variety of other colleges and institutes at the university. WPI is an Engineering and Science Institute with a total enrollment of 2,400 and therefore does not have either the diversity or the problems commensurate with a large college within a large university. The Brigham Young University (BYU) case study has as its major focus the programs operated by a single department with an enrollment of under 1,000 students. The report on Texas A&M (part of a larger case study on Texas Instruments' programs with educational institutions) is confined solely to the Integrated Circuit Design Program, which involves three courses delivered by the University's Electrical Engineering Department.

Brigham Young University (BYU)

BYU's College of Engineering and Technology defines its role in a more comprehensive manner than many engineering colleges. According to BYU representatives, it is no longer possible for one person to master the skills and knowledge once required of engineers alone. More and more, they say, the design, planning, and execution of technical projects (once the responsibility of engineers) requires a team made up of management, marketing specialists, and research engineers (who originate the idea), manufacturing engineers and technologists (who work together to develop the layout and detailed design, test the prototype product, and to plan, design and test the machines or procedures for building a system or its components), and technicians and machine operators (who bring about the actual production). Engineering and "engineering technology" (which is similar to engineering in many respects but is less theoretical and more application-oriented than traditional engineering studies) are seen by BYU representatives as partner disciplines, both of which are necessary to provide the broad spectrum of education and training required to prepare graduates for engineering and engineering related positions in industry.[10] The remainder of this section focuses on the roles and functions of the Technology Department at BYU.

B.S. Programs in Manufacturing, Design, and Electronics Engineering Technology. The design and manufacturing programs were both created in 1960 to fill a perceived gap in engineering education created by the increasingly theoretical nature of engineering curricula that developed in the late 1950's in response to the needs of the U.S. space program. Both the manufacturing and the design program involved careful curriculum planning, which began with a focus on the precise industrial skills and knowledge required of those students who would fill the gap in the engineering spectrum. All three of the BYU technology programs substitute application-oriented laboratory-based courses for the most highly theoretical coursework in traditional engineering disciplines. The function of all three programs is to provide a foundation in theory coupled with practical applications experience, which translates into an instructional program in which fully half of the student's work is practical, "hands-on" experimentation and application. Another function of the programs is to educate students in state-of-the-art industrial practices and techniques -- which, since the mid-1970's has resulted in an increasing focus on computer-aided manufacturing and design. BYU technology instructors stress, however, that while computer-aided methodologies and techniques are incorporated whenever appropriate, the essential focus of the programs is on providing students with a strong foundation in the basics of the three disciplines, augmented by computer techniques currently in use in industry.

The incorporation of computer-aided techniques and coursework into the curricula varies from program to program, reflecting 1) current industrial practices in the three disciplines, 2) the varying amount of conventional manufacturing and design skills required by the different disciplines, and 3) the availability of industrial equipment. Thus, the design curriculum is most suffused with computer-aided techniques and applications both because of the rapid spread of computer-aided design in industrial settings and the large amount of CAD equipment in the department. The design program builds on the basic design and drafting skills and knowledge developed in the required freshman and sophomore courses covering the fundamentals of engineering graphics, mechanical drafting, and principles of descriptive geometry. While computer-aided techniques are taught as *part* of individual lower division courses, fully half of the required courses for juniors and seniors focus *entirely* on computer grahics and computer-aided design. The majority of graduates are employed in industry with such titles as design engineer, CAD engineer, and CAD/CAM engineer.

The manufacturing program, while it is provided with labs well equipped with computer-aided machines, stresses conventional manufacturing techniques for the first 3 years of study to provide the foundation for the computer-aided manufacturing techniques and applications taught in senior and graduate level classes. While the function of the program is to prepare students with the "latest knowledge and skills needed to lead or supervise personnel engaged in manufacturing operations, and to help in the development of new products and processes," the manufacturing faculty emphasizes the necessity of building state-of-the-art (i.e., computer-aided manufacturing) skills on a solid core of conventional knowledge which centers on processing courses (machining, forming, welding, etc.), manufacturing planning and development, and other basics of the discipline. Most Manufacturing Engineering Technology graduates are employed in industry as manufacturing engineers.

The electronics program is the least involved in computer-aided applications -- a reflection of the relatively late development of computer-aided testing (CAT) technology and difficulty in obtaining CAT and process instrumentation equipment.

M.S. Program in Computer-Integrated Manufacturing. It is at the master's level that a solid focus on computer-aided manufacturing and design is emphasized. The function of this program is to provide graduate students, who must have at least a year of industrial experience, with training in the use of specific computer applications (as, for example, robotics) as the basis for the study of integrated manufacturing where a variety of computer-aided equipment is linked in a distributed system. While separate CAD and CAM options are provided, students taking either option are required to take courses from the other and to learn to integrate computerized systems to solve practical, recurring industrial problems.

The University of Michigan

The University of Michigan's College of Engineering defines its major role in the field of computer-integrated manufacturing (CIM) education to be the provision of graduate-level coursework and research opportunities. While it does offer a number of senior-level courses focusing on computer-aided manufacturing theories and techniques, the College does not offer -- nor does it intend to offer -- an undergraduate program in integrated manufacturing. From the college's perspective, students specializing in this area should build on the skills and knowledge contained within existing engineering disciplines. The college's focus on integrated manufacturing coursework is, therefore, aimed primarily at graduate-level engineering students. In 1981, the College established the Center for Robotics and Integrated Manufacturing (CRIM) with the object of coordinating and expanding research and teaching activities in computer-based automation of industrial functions. In the 1982-1983 academic year, a total of 45 graduate students participated in CRIM-sponsored research projects. Engineering faculty members have also been working for the past year to create a new master's program in integrated manufacturing and to develop integrated manufacturing options within existing graduate degree programs. Graduate students currently engaged in integrated manufacturing coursework and research are helped by their advisors to create individual instructional programs from CAM-related courses already in existence.

The College's role with respect to computer-aided design is broader and, at present, more well defined than its role in respect to computer-aided manufacturing. The College offers a master's program in computer-aided design and has established a sequence of courses leading to the degree. Apart from this specialization, CAD coursework is an inherent part of almost all of the college's degree programs. The College's role with respect to computer-aided design is to provide all of its students with a fundamental understanding and the basic skills needed to use the computer as a tool to facilitate engineering design in a broad spectrum of traditional disciplines.

Undergraduate engineering education at the University of Michigan provides students with a strong theoretical foundation in the fundamentals of engineering, mathematics, and science. While some applications courses are available to juniors and seniors, they are generally reserved for graduate students (who have "mastered" the fundamentals). College representatives believe that the College must continue to equip potential engineers with the basics underlying all engineering disciplines. The "information explosion," however, has led to a recent emphasis on the development of life-long learning skills to enable undergraduates to build on their basics once they leave the university.[41] While this new emphasis has not yet been formally incorporated into the curricula, an incentive program has been instituted to provide funds, release time, and short summer assignments to faculty members to develop 1) homework assignments based on open ended problem solving, 2) more laboratory experiments that do more than simply demonstrate basic principles, and 3) interactive computing modules that present the student with branching pathways, some of which are deadends, some of which lead toward solutions to the problem simulated. (This sort of computer-aided learning technique forces students to make decisions in gray areas and to deal with problem definition and redefinition.)

Other colleges and institutes at the university also provide related educational and research opportunities for students interested in pursuing aspects of computer-aided manufacturing. The interdisciplinary Ph.D. program in Urban Technological and Environmental Planning, for example, offers an area of concentration in sociotechnological systems which stresses the interaction between technological and social systems, including automation systems. On the undergraduate level, students may take an American Institutions Program in the College of Literature, Science, and the Arts which offers a course entitled "Industrial Organizations in Transition," which entails summer internships in industry for approximately 60 undergraduates.

Worcester Polytechnic Institute (WPI)

WPI is a private, predominantly undergraduate, engineering-and-science institute. In January 1981, WPI joined with the Emhart Corporation, a $1.7 billion multinational manufacturing company headquartered in Farmington, Connecticut, to form an on-campus research center to work on practical applications problems involved in introducing robotic systems to Emhart's operating divisions. WPI's Manufacturing Engineering Applications Center (MEAC) has now expanded to include other manufacturing firms and has greatly increased WPI's capacity to provide programmable automation education to its students.

Among the many factors leading to the success of the joint venture and to MEAC's recent expansion is careful planning by company and school representatives resulting in firm yet flexible definitions of the roles to be played by Emhart and WPI participants as well as the functions MEAC would be expected to fulfill for both the school and the corporation. The necessary functions required by Emhart representatives, who initiated the venture, were 1) assistance in conducting practical, short-term applications research that would adhere to industrial time-lines and result in completed projects delivered to Emhart within 1 year, 2) a situation that would promote technology transfer -- i.e., that would help the company operating groups that would be the recipients of the systems to understand the development processes and the operations of the systems themselves -- and 3) provision of laboratory and office space on the campus for Emhart engineers to enable them to work in an environment free from production pressures and responsibilities. From WPI's point of view, MEAC had to function within the institute as an educational center that would conform to and support the school's educational objectives.

MEAC has been able to fulfill both sets of functional requirements partially, or perhaps largely, because of WPI's unique approach to engineering education. At WPI, the traditional college lecture course is only one way of developing "professional competence." The primary educational method forming the core of what is now referred to as "the WPI Plan" is the project -- actually a series of projects which require students to apply the information gained from formal courses and other means to tackle practical problems and issues. Two of the projects -- one focusing on a specific application in the student's major field and the other focusing on how technological solutions and problems can affect society as a whole -- are graduation requirements, and students receive credits toward graduation for time spent preparing for and completing them. A large number of students do their project work off-campus at local industries, where they participate in currently operating industrial projects. WPI's industrial project orientation, and the mechanisms already in place at the school that set aside time for faculty and students to engage in such projects, made the school, as one Emhart representative has said, "a natural for industry" and especially for the type of industrial research Emhart required.

The specific roles played by company and school representatives in the MEAC projects are as follows: Emhart supplied all the equipment (including the robots themselves and the peripheral equipment needed to develop the applications) and transported it to WPI; covered all major project costs (which, aside from equipment, included administrative costs, equipment maintenance, and a portion of WPI staff salaries); assigned a project manager to be responsible for the overall operation of the various applications projects; and assigned other engineers and factory workers to aid in the research and development. WPI provided laboratory and office space for the resident Emhart staff; a project administrator; students, faculty, and "resident engineers" specially hired to work on the MEAC projects; workshops, demonstrations, and tours for company personnel; and tuition free coursework for participating engineers who wished to take advantage of the college's educational programs (including work toward M.S. and Ph.D. degrees). In addition, the corporate vice president who conceived of and initiated the program enlisted top corporate support and acted as an arbitrator between the school and the company and between Emhart corporate and divisional employees when the need arose.

Now that MEAC has expanded to include other companies, WPI has incorporated the roles originally assumed by Emhart representatives into formal program mechanisms. The two most important requirements for MEAC corporate membership are 1) that a top corporate executive sit on the MEAC board, and 2) that the company assign an engineer to perform the duties of on-site project director. The students' role in the projects is significant: they work as part of an industrial team and are assigned responsibility for the design, construction, and testing of the parts assigned to them and for working on the integration of the systems as a whole. In some projects, students take full responsibility for developing the complete application.

MEAC now functions as an ongoing part of the educational system at WPI. Aside from bringing in a constant stream of state-of-the-art equipment and providing project opportunities for a number of students, MEAC serves other functions as well. The MEAC equipment (so far, robots only but expected to expand to other forms of programmable equipment as companies with other than robotic system needs join MEAC) is also used for hands-on programming practice by students in the school's computer-aided manufacturing course. Graduates doing robotics research for their theses and faculty conducting individual research also use the equipment. Future plans include using the Computervision equipment in the college's CAD lab for off-line programming of the robots.

Texas A&M University

For the past 2-1/2 years, the Texas A&M Electrical Engineering Department has been working with Texas Instruments on a program that has expanded the scope and level of knowledge available to students in the department's two graduate level integrated circuit design courses. Before the TI program began, students in those courses produced circuit designs on paper, but because of the prohibitive cost of automated semiconductor fabricating equipment, were unable to fabricate the actual circuits to see how their designs worked out in practice.[42] In response to a proposal made by Texas A&M late in 1979, TI agreed to take the students' designs, verify them using computer-aided "design rule checking" programs; fabricate them on TI equipment; and send the finished product -- a silicon wafer containing the student-designed circuits -- back to Texas A&M.

The major function of the program is to illustrate to students in an extremely graphic manner the type of manufacturing errors that can occur when a "theoretically perfect" circuit is designed by someone who has neglected to take the requirements imposed by fabrication and assembly into account. Students learn some of the pitfalls of circuitmaking and, perhaps most important, they learn to think ahead and to consider fabrication and assembly requirements in the original design stage. The program had the direct effect of encouraging professors and students in the Electrical Engineering Department to assemble a computer-aided interactive graphics system to simulate the electrical performance of the students' designs and to run their own design rule checking programs. The designs now submitted by A&M students have far fewer errors than the original students' designs, but the fabrication activity performed at TI is still necessary because there are some errors that do not always appear during the computer verification process.

A direct offshoot of Texas Instruments' participation in the two graduate-level courses is a new senior-level overview course in integrated circuits, made possible by the computer-aided simulation and verification equipment. TI has hired a number of A&M graduates who have taken the program, and A&M representatives have noted increased job offers to graduates who have taken the integrated circuit design courses, increased faculty interest in the program and in semiconductor research, growth in student enrollments, and an increased ability to conduct high level semiconductor research. The Electrical Engineering Department has, for example, recently received a grant to conduct a research program aimed at cutting down the time required to design a prototype integrated circuit.

Texas Instruments has now expanded the integrated circuit design program to four other schools. Because the students' designs and the resulting wafers produced by Texas Instruments can both be shipped, the program is not limited to schools in the direct vicinity of a TI fabrication plant.

EFFECT OF PROGRAMMABLE AUTOMATION ON TRADITIONAL ROLES AND FUNCTIONS OF EDUCATIONAL INSTITUTIONS

While the introduction of programmable automation coursework and research has had a number of effects on the educational institutions studied, some of the institutions showed fewer effects than others, either because they had been introducing programmable automation coursework gradually over the last 10 years, or because they had mechanisms in place that allow them to incorporate new coursework or subjects with relative ease. An important point at the outset is that, in most instances, the cause of the modification of roles and/or functions cannot be limited strictly to the introduction of programmable automation to the curricula. Other general trends in the education sector -- such as the decrease in Federal, State, and foundation funding -- often combine with the introduction of programmable automation coursework to produce a combined effect. In other instances -- specifically in the joint programs with industry -- while the school's desire for programmable automation coursework or research may have been the impetus for the program, the effects on roles and functions may be as much the result of the cooperative nature of the program as of programmable automation itself.

Summary

Following is a brief summary of the major effects of programmable automation on traditional roles and functions. A number of these effects which bear closer examination will be discussed in more detail following the summary.

- Increased Contact with Industry. In all of the programs studied, programmable automation coursework and research has resulted in increased contact with industry, resulting in either modification or contemplated modification of traditional roles and functions (see pp. 90-96).

- Increased Coordination Among Departments and Instructors. In many schools, the research and teaching activities of faculty in separate departments (e.g., Electrical Engineering, Computer Science, and Mechanical Engineering) have traditionally been compartmentalized away from faculty in other departments. The interdisciplinary nature of computer-integrated manufacturing and of specific disciplines within integrated manufacturing (robotics, for example) has brought about cooperative research projects in universities, combinations of courses in once separate departments to form hybrid degree programs in community colleges, and (in one high school program) an interdisciplinary team-teaching approach.

- Increased Attention to Provision of Mechanisms for Upgrading, Retraining, and Cross-Training of Instructors. In a number of instances, the provider of instructor upgrading and retraining is not the school system, but the industrial community. (See pp. 96-98.)

- Increased Attention to Providing Students with Interdisciplinary Coursework. This means, in effect, that students as well as instructors are being cross-trained in a number of disciplines or are, at least, made aware of the need to familiarize themselves with disciplines related to their major field of study. Especially significant in university programs is the necessity of cross-training future engineers who will be responsible for the design of systems in the fabrication requirements imposed by manufacturing processes.

- Refocusing of Curriculum to Accommodate the Systems Approach to Manufacturing. The systems approach involves looking at the entire process of manufacturing, rather than, as is traditional in many technical and engineering departments, focusing on discrete aspects of design or analysis, or on individual mechanisms (see p. 98).

- Retraining for Displaced Workers. A number of the community colleges studied are, or hope to become, involved in the retraining of displaced workers -- either through formal contracts with the UAW and the major auto firms or informally as displaced auto workers and others enroll in programmable automation degree programs. For profit training organizations have also developed programmable automation and other retraining programs for displaced workers, and some universities also believe that they can fulfill the retraining function. A degree of competition for the retraining market appears to be growing up among these education and training groups.

- Participation in Hybrid Entities Bringing Together Industry, Education, and Government to Conduct Research, Education, and/or Training in Programmable Automation. The University of Michigan's participation in the State's new Industrial Technology Institute and the community of Glendale's proposed Technical Training Center are two such entities. (See pp. 99-100.)

- Increased Attention to Developing Life-Long Learning Skills. Rapid advances in programmable automation technology and in technology in general have resulted in the development of formal and informal techniques to aid students in developing their own life-long learning skills. (See pp. 138-9, Common Trends, for further discussion.)

- Increased Attention on the Presecondary Level to Building Basic Skills. Specific attention is being devoted to mathematics as the essential foundation of technical studies.

Because a number of the effects highlighted above have different implications on different educational levels or in institutions with varying educational emphases, the following pages present a more detailed discussion of specific effects.

Increased Contact with Industry

Since increased contact with industry goes hand-in-hand with programmable automation education and research, only the major effects of industrial contact will be discussed in this section. Other effects, which may involve industrial contact but are not necessarily major results of that contact, are discussed elsewhere.

Roles Traditionally Belonging to the Educational Sector Supplemented or Filled by Industry Representatives. In Dallas' Project SEED program -- which was initiated by a Texas Instruments representative who was concerned that Dallas school children did not have the basic mathematics skills or interest to proceed to higher level programs in programmable automation or other high technology areas -- professionals from industry play a major role in supplementing the function of traditional mathematics teachers. On the high school level, the principal of Dallas' Magnet High School plans in the near future to hire retired industrial engineers and scientists as part-time teachers, thus occasioning a modification in the source of teachers to fill traditional roles. In the Eastfield College, Glendale High School, and Glendale College programs -- all of which involve a high degree of industrial participation -- industrial representatives have supplemented or filled traditional educational roles, including program initiation, recruitment and selection of student participants, provision of laboratory facilities, and assistance during laboratory sessions.[43]

Debate over the Proper Roles of Industry and Education (HFCC). Although programmable automation studies and a high degree of industrial contact and focus is traditional to Henry Ford Community College, the proliferation of robotics programs in the Detroit area has occasioned a debate concerning the proper roles of educational institutions and industries in robotics training. Some industrial representatives believe that robotics technician programs should provide training in, or at least exposure to, a variety of commercial robot systems. Other industrial representatives agree with HFCC representatives that it is industry's responsibility to train in the specifics of the particular systems in use in individual firms, while it is the college's responsibility to provide the foundation on which those specifics can be built. This debate still continues.[44]

Gains Achieved by Activities of Individual Faculty Members (BYU). While industrial orientation and close communication with industrial representatives is traditional to the role of the faculty in BYU's Technology Department, the intensity with which individual faculty members play that role is relatively untraditional in a university environment. The three technology programs were planned and created by faculty members who identified the occupational gaps left in industry by traditional engineering education and who fought for accreditation of the practically-oriented technology programs. It was also individual faculty members who kept themselves apprised of current industrial practices; sought industrial advice on curriculum and industrial projects for students; and succeeded in obtaining the computer-aided equipment necessary for the operation of the programs. BYU Technology Department and Engineering Department faculty members also have developed and produced programmable automation software packages licensed by numerous industries; and Technology Department faculty and students are working on a computer-aided simulation training system for use in teaching industrial processes to in-plant machine operators and engineers and to students in educational institutions. While the sale of software and training models to industries is not entirely untraditional for engineering departments, it is indicative of the blurring of educational and industrial roles and functions that may be one result of programmable automation technology.

Bringing the Factory onto the Campus (WPI). At WPI, which has also maintained close contact with industry, the structure of the MEAC program has had the effect of bringing the factory onto the campus. Not only does it bring in state-of-the-art industrial equipment, but it also brings in professional engineers to work with the faculty and students. The recent expansion of MEAC to include other industries apart from Emhart should increase the value of the engineer-on-campus concept by giving students the opportunity to come in contact with professionals from different companies with different needs, perspectives, and operating procedures. Those professional engineers function, in one sense, as on-campus educators from industry. In the Emhart projects, the actual hardware environment of the specific factory operations for which robotics applications were to be developed were either replicated or simulated in the MEAC lab. In addition, the time requirements, the requirements placed on materials and equipment to be used, and the project management supplied by the company engineer also simulated the workplace environment by placing the students in a situation in which real world constraints and necessities held sway. While a large number of WPI students who participate in the school's cooperative education program and/or complete industry sponsored qualifying projects in a factory environment receive a similar kind of educational experience in industrial practices and procedures, MEAC -- by bringing the factory onto the campus -- expands the potential for a larger number of students and faculty to interact with professional engineers on a regular basis.

Possible Shift in Focus of Research Projects (University of Michigan). The University of Michigan's College of Engineering maintains a traditional theoretical focus in undergraduate education, but there have been changes in the focus of some faculty and graduate student research. While the majority of the college's research projects are supported by NSF grants and college funds, and while many cooperative projects are operated in conjunction with nonprofit organizations, a number of faculty and students engage in programmable automation projects conducted for or with industry. The industry sponsored projects, according to College representatives, are likely to increase -- not only because funds from government and foundation sources are decreasing but because the college recognizes that the ultimate laboratory for programmable automation research is in industry.

The college's associate dean for research and graduate studies describes a "model research program," which, it is hoped, will eventually characterize the research undertaken by faculty participating in the Center for Robotics and Integrated Manufacturing (CRIM) and other faculty members as well. The faculty, in this model, would all participate in large "umbrella type" projects (seen as essential to interdisciplinary problem areas like those addressed by CRIM) which would ideally involve technology transfer to industry. Each faculty member would also receive grants for research in a personal area of interest, at least a portion of which would complement the larger umbrella type research project. Faculty would also develop ongoing working relationships with industry and interact with industrial representatives on a regular basis. Grants would include funding primarily for the participation of graduate students. While some of the research currently conducted by CRIM is beginning to take on the look of the "model research program," College representatives anticipate that a long evolutionary period will be required for this approach to become a model for the College as a whole, or even for all programmable automation research conducted by the College.

One reason for the length of time expected for the model research program to become widespread is the divergence of research aims of industry and educational institutions like the University of Michigan. The University is committed to long-term research (usually lasting 5 to 10 years) that promises to have a significant impact on technology or the economy, while the demands of industry usually require shorter projects with specific production and/or design goals. Some industries have committed funds and equipment through the Industrial Affiliates Program operated by CRIM's Robot Systems Division, and some faculty and students have taken on shorter-term projects. Nevertheless, given the sheer size of the institution, it will take time for the College as a whole to define its role in respect to industrially oriented research -- perhaps by identifying long-term research projects with some short term effects or spinoffs.

Changes Occasioned by Industry Project Orientation (Texas A&M). Faculty members in the Texas A&M Integrated Circuit Design program expanded their normal teaching and research roles through their participation. Their responsibility for making sure that the students' circuit designs are completed and verified by the time of the prearranged shipment date to Texas Instruments put them in a situation similar to that of industrial project managers. For their part, the students feel some of the realistic pressures set up by the necessity of meeting industrial deadlines. Texas Instruments, which has recently expanded the program to other colleges and universities, has suggested to those schools that the professors involved be given reduced teaching loads to enable them to accommodate project management responsibilities.

Increased Attention to Provision of Mechanisms for Upgrading, Retraining, and Cross-Training of Instructors

Universities. Computer literacy and, perhaps more importantly, the ability to teach Computer-Aided Engineering techniques to students are not universal among college and university engineering faculty. Most of the universities studied offer workshops and seminars to teach computer skills to faculty members. At BYU, faculty can upgrade their knowledge of industrial practices by taking "professional development leave" to work in industry instead of the traditional sabbatical; at WPI, the increase in student industrial projects involving programmable automation means that the professors who oversee those projects upgrade their knowledge of state-of-the-art practices; and at the University of Michigan, Engineering College representatives are considering ways of providing rewards for industrial experience (methods under consideration are the development of industrial internship programs for faculty and incentives to encourage faculty members to use their sabbatical leaves to work in industry). Mechanisms established in the universities that increase coordination among departments also function as official or unofficial mechanisms for providing cross-disciplinary experience to faculty members. The University of Michigan's Center for Robotics and Integrated Manufacturing, plus other interdepartmental projects involving programmable automation, bring together faculty from a variety of computer science and engineering disciplines. BYU's Computer-Assisted Engineering, Design, and Manufacturing (CAEDM) committee provides a formal channel of communication between technologists and engineers in all the College's departments, and a number of professors coordinate projects in which technology and engineering graduate students work together as part of a research team. The Technology Department -- whose primary focus is on the *implementation* of engineering designs -- has been instrumental in increasing the engineering departments' awareness of the need to produce industrial design engineers who take account of manufacturing concepts and requirements. WPI's plans for its Manufacturing Engineering Applications Center include expansion of its present robotics applications research to research in computer-integrated manufacturing. The CAD/CAM projects that result would require integrating and cross-training faculty who have previously been involved primarily in either graphics or manufacturing processes.

Community Colleges. Attention to upgrading, retraining, and cross-training also exists at the community college level. Henry Ford's Electrical-Electronics Technology program has had an interdisciplinary focus since its inception and includes cross-training in mechanics, hydraulics, and pneumatics. Close coordination among the faculty provides an interdisciplinary framework for each individual faculty member. At both Eastfield and Glendale colleges, faculty members teaching computer-aided design received upgrade training from two sources: 1) vendor training, and 2) on-the-job training in industry.

High Schools. While the instructors in the Glendale High School CAD program also received vendor training and on-the-job training in industry, the robotics and CAD instructors in the Oakland Intermediate School District have had fewer formal retraining opportunities. The instructors now teaching robotics and computer-aided drafting have made progress by reading on their own, by working with industrial experts, by using equipment manuals to teach themselves, and by attending some in-service workshops. Oakland representatives, however, believe that an in-depth, structured program of teacher-training is needed. The drafting instructors did receive some in-service training in the operation of the Tektronix drafting terminals used in the courses offering CAD segments, and the district has assisted by providing tuition reimbursement for a number of instructors who have taken a computer applications course at Eastern Michigan University. District officials believe, however, that State or Federal assistance is needed to enable them to undertake instructor upgrade training on an appropriate scale.

Refocusing Curriculum to Accommodate the Systems Approach to Manufacturing

Faculty at the University of Michigan are working on a new master's degree program in integrated manufacturing to develop engineers who are more process-oriented than in the past and who will learn to approach industrial manufacturing and design by taking the entire design and manufacturing system into account. In the BYU Technology Department, the "systems approach" has been in use from the time the department was established. Design, manufacturing, and electronic technologists take required courses covering the fundamentals of the other disciplines. Design students learn basic manufacturing processes and how to achieve economical production by selecting the proper process, and manufacturing students take a senior-level course which applies the systems approach to an actual industrial project or one which simulates industrial conditions. The Technology Department's master's program in computer-integrated manufacturing focuses directly on the systems approach -- the goal being to teach students to integrate computerized systems in manufacturing environments.

Participation in Hybrid Entities

The University of Michigan is the temporary home of the State's new Industrial Technology Institute (ITI), a nonprofit corporation established by the Governor's High Technology Task Force. The Institute's goal is to become the national center for information, communication, and research on all aspects of "the factory of the future," and its focus will be on practical research and industrial involvement. A number of faculty members from various University of Michigan colleges and departments have participated in ITI planning and development activities, and it is expected that university faculty will continue to participate in the Institute's research on all aspects of integrated manufacturing. ITI was created with the intent of focusing on the application of existing technology; its spirit is, therefore, closer to industry than that of traditional research institutions. A number of faculty members at the university look to ITI as a possible solution to the conflict in goals and orientation between industry and the university (see pp. 93-95) by providing an environment that is neither academic nor private sector but a hybrid of the two.

The community of Glendale's plans for a high technology center also call for a hybrid organization, but its focus would be directed toward education and training rather than applications research and development. The proposed Technical Training Center would be supported by local industries, schools, and government agencies and would be outfitted with equipment to address a wide variety of high technology skills, including computer-aided design and computer repair. The center would be shared by all of the schools in the district and would be available for laboratory work required in college and.

high school classes, for retraining or upgrading of workers currently employed in local industries, and for government funded training and retraining programs. Plans for the center appear to be taking shape quickly. Many education, business, and local government leaders have agreed on the concept; and a major producer of CAD/CAM equipment has expressed interest in the possibility of donating equipment.

PARTICIPATION OF OTHER SECTORS IN EDUCATIONAL PROGRAMS

The programs highlighted in the previous section, especially the cooperatively sponsored programs, illustrate the crucial importance of participation by other sectors in the programmable automation education and research conducted by educational institutions. This section summarizes the ways in which various sectors other than education participate in the degree programs and individual courses examined in the case study series.

Industrial Participation

Industrial participation can take a variety of forms and is dependent on a number of factors, including the goals, objectives, and functions of the education/research activities conducted by the educational institution; the philosophies and objectives of the participating companies; the degree of participation required; the costs (in money, time, and equipment) of such participation, and the perceived returns on that investment.

The following list indicates the range of industrial participation noted in the education and training case studies:

- Donation of funds, equipment, parts, and materials by both user and producer firms.

- Participation in formal Industrial Advisory Committees or in informal advisory sessions. In both instances, industry representatives give advice on overall curriculum content, specific course content, industry and labor market needs, equipment needs, industrial practices, and (in the university setting) industrial research needs.

- Program initiation. Texas Instruments, for example, initiated Project SEED, the Eastfield College program, and the expansion of the Texas A&M program. Emhart initiated the Manufacturing Engineering Applications Center at WPI; and a representative from JPL initiated the Glendale High School CAD program.

- Program sponsorship. This can take a variety of forms -- from the provision of funds and equipment to be used for specific purposes, to active participation in the research and/or educational activities of the program (as illustrated by the MEAC program, the Glendale Coordinated Funding program, and the Texas A&M program, to name but a few). The discussion (on pp. 106-109) of industry participation in joint programs details specific activities of industrial sponsors.

- Participation on school boards and educational task forces. TI representatives on the Dallas school board aided in curriculum development for the Engineering/Science Magnet High School; JPL representatives on the Glendale School Board initiated the High School CAD program.

- Encouragement of company employees to 1) teach courses on a variety of educational levels, and 2) speak to groups of high school and college instructors about industry's needs and practices. TI, Westinghouse, JPL, and others encourage employees to engage in such activities.

- Research project sponsorship and participation. BYU students, for example, have participated in joint research projects with industry on plant layout and materials handling, group technology and coding studies, and machinability studies. University of Michigan undergraduates and graduates are working under the direction of faculty on a joint project -- "In Process Sensing and Control of Computer-Aided Manufacturing" -- supported by a consortium of industries. At WPI, over half of the technical projects (and a significant number of the sociological projects) required for graduation are sponsored by industry and often take place at industrial sites. A growing number of the so-called "qualifying projects" are in the field of programmable automation.

- Cooperative education. All of the colleges and universities operate cooperative education programs. These programs benefit students by giving them on-site industrial experience and a modest income. They benefit the companies by giving them an opportunity to hire exceptional graduates whom they have observed at close hand.

- Instructor upgrading and/or retraining. A number of CAD/CAM equipment and software vendors provide free training to instructors who will be using their equipment as part of classroom and laboratory instruction. In addition, a number of the user firms and one producer firm hire instructors during the summer months to provide those instructors with state-of-the-art industrial experience and/or to get the benefit of the instructors' (usually, university professors') expertise in a specific field.

- Mutually beneficial activities. BYU students, for example, are working on a project to write user-friendly software for Computervision in exchange for free maintenance of the school's Computervision hardware (maintenance contracts are extremely expensive -- usually 1 percent of the purchase price of the equipment per month). CADAM exchanges software licenses for similar student and faculty services. Apart from the obvious mutual benefits to the schools and the companies, the students engaged in the projects receive valuable experience.

- In-class lectures by industry representatives and provisions for field trips to industrial sites. This type of participation is especially valuable to high schools, where equipment is often not state-of-the-art and where instructors may, in some instances, have less industrial contact than their post-secondary colleagues.

Apart from the instances of industrial participation highlighted above and on pp. 103-109, one other instance deserves mention. Large scale corporate giving programs on the IBM model (IBM will award a series of grants to university engineering schools to develop new curricula in manufacturing techniques) indicate a corporate awareness of the long term benefits of helping universities develop the coursework and obtain the equipment necessary to train engineers in interdisciplinary computer-aided manufacturing skills. Apart from the direct benefits to grant recipients, a significant indirect benefit has been noted by some universities that applied for the grants: in at least one of the universities visited, the IBM announcement provided the school with the impetus to begin the work of integrated manufacturing curriculum planning sooner than was originally anticipated. Some of those planning efforts may come to fruition whether or not the school receives a grant.

Industrial Sponsorship of University-Level Research and Special Continuing Education Programs for Professional Engineers.

In addition to benefitting from industrial participation in the forms mentioned above, the three university programs studied in depth have instituted formal mechanisms to secure industrial support and participation.

- BYU's "Alliance with Industry Program," the University of Michigan's "Industrial Affiliates Program," and WPI's Manufacturing Engineering Applications Center (MEAC) support programmable automation education and research activities by contributions paid annually or biennially by participating companies. MEAC is different from the other two programs by requiring that the companies participate actively in the research (sending an engineer to MEAC to be the project manager), and by the practical, short-term nature of the research and development aimed specifically at implementing robotic applications on the member companies' plant floors. BYU's and Michigan's programs are more general in nature. The industrial funds and equipment support a variety of educational and research activities related to computer-aided manufacturing, design, and engineering. In return, the companies in the University of Michigan program receive research reports and publications, progress reports on research funded by the program, and licenses for internal use of hardware or software developed under the program. The BYU program participants receive licenses for software developed by university faculty, help in solving special industrial problems, research results, and seminars for technical personnel. Companies participating in both programs also have access to students working on programmable automation research and coursework.

- The three universities also operate special continuing education programs for professional engineers from specific companies, all of which were initiated by the industrial participants. The program operated by the BYU Technology Department for Western Electric is the most extensive of the three. Approximately 60 Western Electric employees (primarily engineers and managers) travel to BYU for 5 weeks each summer for 5 years to take specially condensed graduate-level courses in computer-aided manufacturing. The majority of the 60 employees have elected to enroll formally in the department's Computer-Integrated Manufacturing master's degree program, which can be completed by taking two courses each summer for 5 years and submitting a master's thesis. The University of Michigan's Bendix Update Program is designed for Bendix engineers and engineering managers who lack computer skills and knowledge. Participants attend seminars and workshops for a few weeks in the summer at the Ann Arbor campus, attending such short-courses as numerical methods, computer technology, finite element analysis, control systems, microelectronics, computer graphics, and a CAD/CAM overview. Emhart has used the resources at WPI's Manufacturing Engineering Applications Center as part of the corporation's Technical Development Program -- an annual program for Emhart engineers that focuses on technological issues for the 1980's and 1990's. The participating engineers spend a day at WPI attending workshops on robotics and learning programming basics at the MEAC lab. WPI also offers similar Technical Development Program workshops to employees of other firms that participate in MEAC.

Participation by Other Than Industrial Sectors

For the most part, military organizations and State, Federal, and local government participate in the programs studied by providing funding for research, equipment, and program operation. Other providers of research grants include the National Science Foundation, other foundations, and nonprofit organizations. In the special instance of the California Coordinated Funding Project and its successor, the Investment in People Initiative, a number of Federal, State, and local government agencies participated in a more direct manner. Their participation will be discussed in the "Cooperative Program Participation" section below.

A number of educators interviewed believe that the media have also played a role in their programmable automation programs (especially robotics programs) -- sometimes entirely to the benefit of the program, sometimes playing a less than beneficial role. Local and national media attention given to the Oakland High School Summer Robotics Program produced a number of positive results. The publicity not only helped to convince school board officials of the viability of high school programs in robotics and other high technology areas, but also generated the beginnings of a communications network between the Oakland Intermediate School District and other schools both in- and out-of-state. The vocational education curriculum specialist who coordinated the program has received numerous letters and calls from high schools, colleges, universities, and industries from across the country, all of which are either interested in establishing programs or have already done so. The local publicity also increased student interest in other programs offered in the district's vocational education centers. On the other hand, some colleges and university representatives have noted that a number of entering undergraduate students pursuing robotics studies have only a vague notion of what technical education in that area entails and are enamored of the mystique of robotics generated by media coverage. In most instances, this does not present an overwhelming problem. It is, after all, the traditional role of education to mold unformed interests by guiding students toward educational programs that will help them to define and refine those interests in a reasoned manner. Some postsecondary education representatives in the Detroit area, however, express fears that, within the next 2 or 3 years, the area will become glutted with aspiring robotics technicians, many of whom may not be able to find jobs in the field. At least four community colleges in the metropolitan Detroit area currently offer robotics programs, many of them with long waiting lists of applicants. Some college representatives believe that a number of these students, if they are not union members, will have limited employment opportunities in the area, while others, who are laid-off union workers (many with [illegible]ilies) may discover that their economic situation does not permit them to complete a 2-year course of study.

Cooperative Program Participation

While all of the educational programs covered in the case study series have had some degree of participation from other sectors, five of those programs could be characterized as joint ventures in which government agencies and/or industrial firms have assumed a high degree of involvement in program operation. Those are 1) the Glendale High School CAD program, 2) the Glendale Coordinated Funding Program, 3) the Eastfield College Printed Wire Board Program, 4) WPI's Manufacturing Engineering Applications Center, and 5) the Texas A&M Integrated Circuit Design program. The specific roles and functions of the industry and government representatives have been outlined in the Roles and Functions section of this report. However, it is instructive to look at the joint programs as a group and to note the general types of participatory roles played by industry and government.

Industry Participation in Jointly Operated High School and Community College Programs. The industrial participants fulfilled some or all of the following functions:

- Program initiation;
- Recruitment, selection, and hiring of student participants (this applies only to the college programs);
- Provision of laboratory space, equipment, and employee assistance during laboratory sessions at industrial sites;
- On-the-job training or cooperative education opportunities for students (college programs only);
- Upgrading or retraining of instructors through vendor training and/or OJT at the industrial site;
- Assistance in curriculum design;
- Assistance in helping the schools obtain equipment or donation of equipment;
- Ongoing program support through representation on Industrial Advisory Councils or School Boards.

It is notable that Texas Instruments and JPL, the major industrial participants in the programs, have similar philosophies about their relationships with educational institutions. Texas Instruments representatives describe the firm's philosophy as one of "enlightened self-interest." That description applies to JPL as well. Representatives from both organizations believe in making both short- and long-term investments in the educational system, which, they believe, will ultimately produce significant returns for industries by lightening their training burden and easing their hiring difficulties. In addition, they both operate on the principle that industries' needs will not be met unless industrial representatives participate actively in the educational process by making their needs known and helping the schools fill those industrial needs that also meet the philosophical objectives of the schools.

Industry Participation in University Programs.

Although the programs at WPI and Texas A&M are different in nature -- one being an applications research effort with educational spinoffs, the other being an educational program that has resulted in increased research capabilities for the school -- there are some common features. According to educational representatives at both schools, the success of their programs was due, in large part, to the commitment of one or more company representatives who devoted time, effort, and money to the programs' operation and continuance. Another common feature is the industrial project-oriented nature of both programs. WPI's project orientation was established well before MEAC was founded. Faculty at Texas A&M, on the other hand, found themselves placed in the position of being project managers -- a new, and according to them, educational activity. Other common features include hiring of participating students by the companies and an increase in programmable automation teaching and research capacity in both schools.

Government Participation: California's Coordinated Funding Project.

The State-level coordination and sponsorship provided both the impetus and the funding resources necessary to give Glendale College and the five other participating colleges (or, in some cases, consortia of colleges) the opportunity to establish high technology programs. The object of the State-level sponsors was to demonstrate the feasibility of coordinating both funding sources and public and private organizations to support employment and training projects which would also build the educational capacities of the participating schools. In addition, the individual programs provide models of local planning and coordination that could be duplicated throughout the state. The State-level coordination was also a pilot test of the abilities of State agencies to improve local responses to high technology education and training needs by pooling and coordinating their resources. On the local level, the success of the Glendale program in meeting its goals was aided by the previously established linkages between the college, the Private Industry Council (PIC), and local business and industry. The relationship between the PIC and the college is a long standing one, since the college regularly serves under contract to the PIC as the deliverer of classroom instruction and skills training for Private Industry Council training programs. The PIC chairman, as mentioned previously, is a section manager at JPL and also serves on the Glendale School Board. The success of the local-level computer-aided design program, then, resulted from the synergistic relationship between the PIC, the college, and industries like the Jet Propulsion Laboratory. It derived also from the leadership of individuals like the JPL section manager, whose activities in other arenas provided him with both the multiple perspective and the position to effect the coordination called for in the State's Coordinated Funding Program.

NEEDS, PROBLEMS, AND TRENDS

In many cases, needs, problems, and trends overlap. For example, representatives from all of the institutions visited stressed the need to develop instructional techniques that build the students' individual ability to continue the learning process throughout their professional lives. That development of what is most commonly referred to as "life-long learning skills" is both a need and a trend. The need for computer-aided equipment and adequate laboratory facilities is also a significant problem. Therefore, while this section does categorize issues into the three basic divisions of needs, problems, and trends, it is important to bear in mind that the categories are not strictly separable.

Needs

Among the most pressing needs of educational institutions now offering or planning programmable automation coursework are the following:

- Development of industry relationships that are appropriate to the long- and short-term goals of both the school and the industries.
- Increased communication among educational institutions offering or planning for programmable automation curricula; increased communication between the educational and industrial sectors; and mechanisms to communicate to prospective students explicit information about the focus and character of the education provided by specific institutions. (See Conclusions for further discussion and recommendations.)
- Careful preplanning and advance preparation, including labor market studies and needs assessment (especially in the case of occupationally oriented high school and community college programs whose graduates will look for employment in local industries); continuous program monitoring to ensure that current needs are being met.
- Up-to-date texts and curricular materials.
- Increased emphasis on cooperative education programs and/or development of project-oriented classes that either simulate industrial projects or offer students the opportunity to participate in actual industry projects.

Other issues mentioned previously under "Effects of Programmable Automation" could be characterized as trends in the institutions studied that had developed ongoing programmable automation programs. Those issues are, however, also significant needs for institutions planning on establishing such programs:

- Increased coordination among departments and instructors in those disciplines contributing to programmable automation curricula.
- Increased attention to providing formal mechanisms and informal opportunities for upgrading, retraining, and cross-training instructors.
- Increased attention to interdisciplinary studies opportunities for students.
- Refocusing of curricula to accommodate the "systems approach" to manufacturing in engineering schools offering degree programs or options in programmable automation, specifically in programs focusing on computer-integrated manufacturing.

Problems

The following list briefly summarizes the major problems affecting the introduction and continuance of programmable automation studies in educational institutions.

- Lack of adequate funds, appropriate computer-aided equipment, and adequate laboratory space.
- Difficulty in locating and hiring instructors with appropriate academic and, in some cases, industrial backgrounds; difficulty in retaining instructors whose qualifications make them attractive to industry.
- Limited enrollment capacity, often resulting in long waiting lists of students interested in applications-oriented programs and a relatively small number of program graduates.
- Difficulties in absorbing the additional coursework and laboratory requirements for programmable automation studies (especially computer-aided manufacturing) into already demanding traditional 2-year technician programs and 4-year engineering programs. The 4-year engineering schools seem to have the most severe problem in this regard. WPI has attempted to address the problem by creating flexible mechanisms that allow students to complete required traditional engineering subjects in a variety of ways, including self-paced individually prescribed instruction courses. The University of Michigan, along with a number of other schools contacted, reserves specific emphasis on integrated manufacturing for graduate degree work. In all instances examined, the comprehensive study of computer-integrated manufacturing (the systems approach) is reserved for graduate programs.
- Specific problems of large, research-oriented "multiversities." Among these are problems relating to the tenure system, problems of coordinating research activities, and the divergent aims of university and industrial research. The problems of divergent goals and coordination are addressed on pp. 94-5. The tenure system contributes to those problems and can also prevent untenured faculty from taking advantage of opportunities to gain industrial experience that may aid them in programmable automation instruction and research. Under the "publish or perish" requirement which characterizes the tenure system at most major universities, untenured faculty members often have little or no incentive to take time from long-term projects that result in scholarly publications to work in industry or engage in short-term industry-oriented research. In addition, untenured faculty often have more incentive to conduct independent research than to participate in large projects where their individual contribution is diffused.
- Competition among schools in various arenas relating directly or indirectly to programmable automation studies, including 1) competition for resources and

students, 2) competition between schools at different educational levels or offering differently structured programs (for example, technology programs as opposed to engineering programs) due to a lack of agreement over the type of educational program necessary to prepare students for specific industrial occupations. Engineering technology graduates, for example, have been hired as technicians in some firms and as engineers in others. Some postsecondary education representatives from 2-year technical programs express concerns that less highly trained high school graduates may compete for jobs with their own graduates who have 2 more years of specifically focused technical training.

Trends

- A recent tendency for some "better engineering students," who previously may have gone into other engineering fields, to enter manufacturing programs or to take manufacturing coursework preparing them to become manufacturing engineers, CAD/CAM systems engineers, or to work on manufacturing research.
- A tendency for engineering professors who have not maintained state-of-the-art level knowledge to carry the basic undergraduate teaching programs, while those whose research and consultation activities bring them up to or at the leading edge of the field teach upper division and graduate courses focusing on programmable automation. In some environments, this is viewed as a problem as well as a trend.
- Establishment of mechanisms, or discussions of introducing mechanisms, to replace the traditional college and university sabbatical leave with a "professional development leave" entailing work experience in industry.
- An increasing awareness among college and university faculty members that undergraduates and graduates preparing to become design engineers must have some experience with or knowledge of manufacturing processes -- and, conversely, that prospective manufacturing engineers must be conversant with design principles.
- Establishment of masters' level degree programs combining business management coursework with engineering or technology coursework to educate future industrial systems managers.
- Increased attention to developing educational techniques that build the students' abilities to engage in life-long learning.

Specific Needs, Problems, and Trends of Education or Research Programs Operated Jointly with Government and/or Industry

This section focuses on those joint ventures that have achieved a degree of success. Thus, in large measure the needs have been met and the problems overcome. This section will therefore examine those programs without making the same distinctions between needs, problems, and trends as has been useful in the previous section.

Flexibility and Close Coordination.

In many instances, even the most careful preplanning could not obviate startup problems and periods of frustration. Even in the best planned programs, there are bound to be periods where the production goals of industry and the industrial procedures that support those goals come into conflict with educational goals. Flexible planning that takes account of those differences can result in initial compromises that give the program an increased chance of success. Close and continual coordination and an attitude of flexibility can get over the rough spots that may occur midstream and enhance the chances for continued success.

In most of the cases observed, close coordination required geographical proximity. In the WPI program, for example, Emhart engineers moved on-campus to be project managers, and a corporate vice president traveled back and forth between the MEAC lab and the Emhart plants to make sure that everyone's concerns were being addressed and that individual frustrations did not reach unmanageable proportions. Both the Eastfield College and the Glendale College programs required that the schools be within easy driving distance from the industries, since students had to travel between plant and school two or more times a week. Texas A&M, on the other hand, is almost 200 miles from the Texas Instruments facility which sponsors the program. While the TI representative made a number of trips to the school during the initial stages of the program, most coordination between the plant and the school was conducted by telephone.

Finding the Proper Fit.

In the most successful of the joint endeavors, both industry and academic representatives spent time and energy to see to it that there was a good match between school and industry. In addition, the specific activity undertaken -- whether research, a joint education and training program, industrial assistance in coursework, or the opening of industrial labs to students -- must have specific benefits for both partners without compromising the long term goals or general role of either partner. The benefits to education, most often seen in the form of access to equipment and help with curriculum design, are relatively obvious. Benefits to industry range from the short-term (hiring of program graduates, some of them specifically trained in company procedures) to the long-term (building the schools' internal capacities so that they can eventually produce a job ready pool of graduates). Whereas close coordination requires continual planning, finding the proper fit requires careful preplanning, including well defined objectives and open communication about individual needs, requirements, and limitations.

Established Modes of Operation that Lend Themselves to Cooperative Endeavors

WPI's requirement of projects for all students, for example, drew on the school's established mechanisms (faculty expertise in project direction; time set aside in the students' schedule for project work; and an institutional mind set that could accommodate the demands of industrially oriented research projects) that enhanced MEAC's chances of success. The preestablished mechanisms that laid the foundation for the CAD training program at Glendale Community College were the already established linkages created by the Private Industry Council between the school and local industries. While such established modes of operation are not an absolute necessity, it seems that programs operated in schools and communities where these exist have an increased chance for success.

A Company Champion.

A pivotal figure in all of the cooperative programs studied is a manager or executive from the industrial side of the partnership whom one school representative described as "a company champion." In all cases, the company champion vigorously supports the project inside the company, coordinates school and company efforts, and devotes large amounts of time and effort to the project. Many school representatives noted that, without the company champion, their projects or programs would have had minimal chances for success.

III. SUMMARY OF FINDINGS AND CONCLUSIONS

The two previous sections illustrate the variety of approaches taken to programmable automation education and training programs; the differing roles and functions of programs in a variety of institutions and organizations; the effect of programmable automation on traditional education and training roles; and the needs, problems, and trends observed.

Up to this point, the industrial and educational sectors have been treated as separate entities. Taken as a whole, however, the individual programs could represent a continuum of education and training through which an individual might proceed in step-by-step fashion from primary school through professional training in industry. Beginning in the primary grades with a program like Project SEED, which builds basic mathematics skills and attempts to create an interest in mathematics as the basic building block for further technical education, the imaginary individual could then proceed along one of two paths. He or she could proceed to technical, occupationally-oriented high school programs like those offered by the Oakland or Glendale school districts and which provide fundamental trade skills and CAD or CAM familiarization. From there, the student could move into a union-apprenticeship program or to a 2-year technician program like that offered by Henry Ford or Eastfield Community Colleges and enter the workplace as a technician trained in basic technical disciplines (such as electronics, mechanics, drafting) and generalized programmable automation skills (such as robotics, for example, or computer-aided design). Once in the workplace, the individual could encounter vendor training, where he or she would learn the basic operation, programming or maintenance of the specific equipment used by the plant and, after that, take formalized classroom/ laboratory training to learn how that equipment is used in the specific application particular to the plant. A similar progression could be imagined for the prospective engineer, who could proceed to the Engineering/Magnet High School such as the one in Dallas through engineering or technology education at one of the universities profiled, to on-the-job and formal training in advanced CAD/CAM user- and networking-techniques provided by a user firm.

This "continuum" of education and training, however, is little more than an academic exercise -- an idealization based on programs that are rarely available in a single locality. The educational institutions and union and industrial training organizations examined in the case study series were chosen as subjects because they had established ongoing programs in programmable automation that have either already met or have the capacity to meet comprehensive or specialized education or training goals. While there are a number of other *training organizations and educational institutions* throughout the country that have also established such programs, an official OTA survey showed that only 22 percent of *companies* currently using programmable automation provide or sponsor training programs for employees, and an unofficial telephone survey conducted by this researcher indicates that a large number of educational institutions are just beginning to address the need or have not yet been able to do so. It could be said, then, that the education and training continuum *does* exist, but because the programs exist in far flung pockets or islands, the opportunity for individuals to tap into that continuum may, at present, depend on luck, persistence, or a combination of the two.

There is no systematic, nationwide mechanism to provide that continuum of education and training and no firmly agreed upon set of objectives for each type of institution or organization fulfilling education and training functions. However, instructional providers at various levels should be able to *assume* that providers on previous levels have fulfilled their functions. Students in 2-year college technician programs, for example, must have adequate mathematics skills to succeed in such programs, and it helps if they have had basic mechanics, electricity, drafting and computer familiarization coursework in high school. Trainees in vendor or in-plant programmable automation courses must have core trade skills in order to make proper use of the machine-specific or application-specific industrial training programs. However, instructional deliverers at various levels have noted that they must often provide remedial education or training to ensure that all the students have an adequate foundation. According to Dallas high school representatives, over 60 percent of entering freshmen must begin with remedial mathematics. Community college representatives have noted that poor grasp of mathematics is a significant cause of attrition in technical programs. Some union and industry training organizations have found that the need for programmable automation skills training has brought to light a concurrent need for refresher training in core trade skills.

Summary of Education and Training Program Functions

Since this summary is drawn solely from the universe of the 14 reports that make up the case study series, the functions mentioned at various levels are only those observed in the specific institutions and organizations examined. Therefore, while it is known that a number of primary schools, for example, provide computer familiarization programs, computer literacy is not mentioned under primary education functions since it was not a part of the primary school program studied.

The functions observed at the various levels of educational programs are as follows:

- Primary -- building basic mathematics skills and an interest in mathematics as a foundation for further technical studies.
- High School -- computer literacy (computer history, applications, basic programming); preengineering; basic computer science; computer-aided drafting or robotics familiarization, either as part of vocational education courses in drafting, electronics or other vocational programs or as stand-alone courses; career awareness.

- Community Colleges -- 2-year degree programs in programmable automation (robotics, computer-aided design) for technicians; short-term (1 semester) industrial training programs in computer-aided design; long-term (4 semester) workstudy programs geared to specific industries' needs; career counseling; articulation processes with local colleges and universities.

- Universities -- 4-year engineering technology programs in manufacturing, design, and electronics, stressing programmable automation founded on conventional skills; master's program in computer integrated manufacturing (Brigham Young University). Practical, shirtsleeves engineering education providing on- and off-campus industrial project opportunities in programmable automation; computer-aided design at all undergraduate levels, computer-aided manufacturing for upper division students (Worcester Polytechnic Institute). Engineering education stressing computer-aided design as an inherent part of all engineering disciplines, computer-aided manufacturing courses offered to upper-division students, but with focus on computer-integrated manufacturing for graduate students (University of Michigan). Graduate and upper division coursework in integrated circuit design offering industrially-oriented project experience linking design to knowledge of fabrication processes (Texas A&M).[45]

- Apprentice and Journeyman Training -- 4-year apprentice programs operated by college or industry/management sponsored training organizations: programmable controller training for industrial electricians at apprentice and journeyman levels.

- In-plant Training -- job-specific class room/laboratory training focused on precise application needs of the plant. Programs covered include automated materials handling; CNC operations, programming, and maintenance; programmable controller maintenance; robot programming and maintenance; operation and maintenance of specialized computer-aided equipment for specific functions; computer-aided design; computer-aided analysis programs for engineers; networking for computer-integrated manufacturing systems; familiarization for managers.

- Vendor Training -- machine- or system-specific classroom/laboratory training, usually not applications oriented. Programs covered include CNC programming, operations, and maintenance; robot operation, programming, and maintenance; machine control programming and maintenance; vision system operations and maintenance; computer-aided design; operations and maintenance for automated semiconductor equipment.

Program Capacities

This section addresses the capacities of various segments of the educational and industrial sectors to provide programmable automation skills and knowledge, emphasizing specific strengths and weaknesses of the programs offered by each sector.

Educational Programs

Primary. Although primary school programs like Project SEED and primary and high school programs that teach computer familiarization and basic technological literacy do not have an immediate focus on programmable automation, it is these programs that may have the greatest potential impact. If Project SEED, for example, can produce students who are interested emough in mathematics to take more advanced high school math and to succeed in the mathematics-based science and technology programs in high schools, it may increase the number of high school graduates interested in and capable of graduating from the postsecondary technology and engineering programs. In its first year of operation, Project SEED served over 2,000 students; current plans call for the project to spread through the entire Dallas Intermediate School District within the next 2 years. The basic strength of such programs is that they can be organized to reach all students. Even if they create a continuing interest on the part of only a portion of those students, those whose interest is engaged will have an opportunity to begin their technical education at an early age.

High School. High School programs can 1) prepare students for postsecondary education by providing 'fast track' science and engineering education like the Dallas Magnet High School or enable college-bound students to develop vocational and technical skills while also taking academic coursework, or 2) familiarize students preparing for entry-level industrial jobs with robotics, computer-aided drafting, or other programmable automation skills. According to some postsecondary education representatives, it is not possible to provide adequate entry level programmable automation skills on the high school level, partially because of the limited time available in high school programs for vocational education coursework, and partially because a solid foundation of basic academic and vocational skills is needed to provide the groundwork for programmable automation studies. High school representatives interviewed, while they stress continued education for all vocational program students, also note that a signficiant number of their students have the intellectual capacity to take postsecondary coursework but cannot afford to do so. These students, they say, would "fall through the cracks in the educational system" if they were not given the opportunity to at least become familiar with high technology fields like robotics and computer-aided drafting.

While high school programs may not be able to prepare workbound students to become full-fledged robotics technicians or CAD operators, they can conceivably prepare students to become technician assistants, CAD lab assistants, or help them to succeed in union apprentice programs focusing on electrical or mechanical maintenance skills. In addition, such high school programs can encourage workbound students to continue their education part-time to prepare themselves for upgraded technical positions. Significant strengths of the high school programs studied are their flexibility and the willingness of instructors and students to take innovative approaches. Instructors in the Oakland Schools, for example, are experimenting with introducing CAD in the early stages of drafting instruction. This type of experimenting, if successful, may help to solve a current problem noted by industrial trainers, which is that drafters and designers trained in manual techniques have a tendency to use computer graphics to achieve the same results as with manual methods -- thus not taking full advantage of the capabilities of the new computerized tool. Another benefit noted by high school instructors in the Oakland County summer program in robotics is that students attracted by the "glamor" of robotics can be encouraged to study "unglamorous" subjects like electricity because they must know it to continue with robotics studies.

Community Colleges. A major role of community colleges is occupational preparation, defined by one community college representative as part of the "mission to provide the community what it needs." All of the 2-year colleges studied are both aware of and responsive to the needs of the local industrial community and illustrate that responsiveness by soliciting industrial advice on curriculum and on equipment needs, by requiring that their instructors have previous industrial experience in their disciplines, and by encouraging individual instructors to maintain contact with industry representatives. While remaining responsive to industrial needs -- and, in the case of Henry Ford, actually anticipating those needs -- the colleges also balance the needs of their students and the community as a whole with those of local industries. Although that balancing act occasionally results in programs that do not satisfy all of the stated needs of all local industry representatives, the colleges studied were all either currently meeting many general programmable automation needs in their communities or building their internal capacities to do so.

The major strengths of the community colleges as a whole are 1) the practical, hands-on orientation of their programs; 2) the industrial experience of the instructors, all of whom devote many hours of their "free" time to the programs and the students; and 3) their active use of formal and informal industrial contacts to shape the curricula to meet industrial needs insofar as those do not conflict with the general goals of the colleges. The colleges' focus on practical, technician-level coursework makes them excellent vehicles for the growing-need to retrain displaced workers. One of the colleges is currently operating a UAW retraining program and another is being considered as a retraining program operator.

The major weaknesses of the community colleges derive primarily from lack of adequate funding to purchase industrial quality programmable automation equipment in the quantities necessary to train the numbers of students interested in robotics and CAD programs. While Eastfield has just built a new CAD lab, while Henry Ford will soon build a new wing containing automation labs, and while Glendale representatives feel confident of their ability to leverage funds to build a lab if the community's Technical Training Center is not established, inadequate lab space promises to be a continuing problem. Adequate computer-aided design training requires a great deal of terminal time for each student, and robotics training, likewise, requires hours of hands-on experience. The likelihood is that, as the labs expand and more equipment is acquired, the student enrollment in the programs will increase and laboratories and equipment will continue to be strained. This is already occurring at Eastfield. While enrollment control is an obvious solution, such a measure may mean that inadequate numbers of students are trained to meet the growing need in some areas. Glendale representatives believe that, within the next five years, local community colleges without adequate CAD labs and equipment will be failing to meet one of their major goals -- the preparation of adequately trained entry-level drafters and designers.

Universities. The programmable automation focus of each of the three institutions studied in-depth is quite distinct from that of the other two.[46] The greatest strengths of the University of Michigan are the high calibre of its faculty and students; the diversity of its computer-aided engineering offerings; the varied opportunities for students to engage in interdisciplinary studies both within the Engineering College and in a variety of other colleges and institutes in the university (which bring the perspectives of economists, sociologists, organizational psychologists and other experts to bear on technological issues); and the high-quality advanced research opportunities available to graduate students. One major limitation derives from the vast scope of the College's efforts; coordination and communication (both within the College and between the Engineering College and the numerous institutes and colleges involved in some manner with programmable automation) are difficult, and the sheer size of the College faculty (approximately 300) and student-body (approximately 5,500) makes agreement on instructional goals and curricular planning difficult. The theoretical focus of the undergraduate coursework and College's difficulties in expanding its small cooperative education programs (serving only 54 students as of spring 1983) may be viewed as limitations in respect to undergraduate students who intend to work in programmable automation engineering fields but who do not intend to pursue advanced degrees. Appropriate counseling before entry to the university and/or a strengthening of the co-op program could counteract the latter two limitations. The Engineering College's major limitation is lack of funds to purchase and maintain equipment, update laboratories, and hire new faculty and technicians to support its various programmable automation research activities and goals.

The current strength of the Brigham Young University technology programs is the result of the faculty anticipation of the present industrial need for university graduates skilled in computer-aided manufacturing and design long before it reached its present proportions. The faculty is thus now able to incorporate many state-of-the-art techniques as they became apparent in industry. The master's program in computer-integrated manufacturing produces graduates trained in the systems approach now cited as crucial by industrial representatives. Other strengths are integral parts of the programs as originally designed -- a heavy concentration on practical laboratory experience, undergraduate opportunities to participate in industrial projects, and state-of-the-art computer-aided equipment available to undergraduates in college laboratories. A major limitation is the size of the programs (a recent policy of enrollment control will reduce the number of technology students from almost 1,000 to 900 over the next 5 years). Some of the students believe that the lack of understanding on the part of some industrial recruiters of the precise nature of the technology curricula at BYU limits, not their potential to be hired, but the type of position they are hired to fill. However, while a minority of technology graduates are hired to fill technician positions, the vast majority are hired as manufacturing or design engineers and some are hired as CAD or CAD/CAM systems managers. Furthermore, surveys show that many BYU Technology graduates in industry have been promoted over the heads of new hires with engineering degrees because they needed less on-the-job training than many traditionally educated engineers.

While the University of Michigan reserves its major emphasis on computer-aided manufacturing for graduate programs, and while the BYU has created undergraduate technology programs (which substitute practical coursework in manufacturing and design -- both conventional and computer-aided -- for the most theoretical of the ABET-required[47] engineering courses), Worcester Polytechnic has taken another approach. WPI students are not required to take the lock-step series of courses required in the majority of engineering colleges. Instead, they are informed from the outset that specified topics must be covered to prepare them for the competency examination which must be passed as a graduation requirement, and these topics correspond to the courses recommended by ABET. Students may fulfill graduation credit requirements by traditional lecture courses, independent study, project work, or "individually prescribed instruction" (a form of self-study in which students use a variety of instructional methods, including conventional texts, audio-visual aids, experiments, and problem-solving techniques to progress through subject-work at their own speed). Although WPI does not, at present, have as many course-offerings in programmable automation as either BYU or UM, the institute's innovative internal mechanisms -- including the projects, the individually prescribed instruction (which has been used effectively in computer-aided design courses), and the Manufacturing Engineering Applications Center (now a part of the schools internal mechanisms) -- give it the flexibility to move rapidly to meet the need for computer-aided engineering education. In addition, WPI is now developing a master's degree program in manufacturing engineering which will have a computer-integrated manufacturing option.

WPI emphasizes industry-oriented applications research; BYU technologists engage in both long- and short-term industry-oriented research and development; and UM stresses long term research of potentially high technical or economic impact where technical success is uncertain (thus filling a need that industrial researchers may not have the luxury to address). The programmable automation education offered by the three institutions ranges from a concentration on industrially-oriented conventional and computer-aided engineering technology, to project-oriented, competency-based undergraduate education, to graduate education stressing breadth and integration in computer-integrated manufacturing and design. Each of the three universities address a different piece of the need. Thus, while it indicates that a single institution may have its own structural, financial, and other limitations, the spectrum of the offerings shows that it is possible for university-level institutions, taken as a whole, to meet many major needs.

Nontechnical Capacities of Educational Programs. Another strength of the education sector is that is has the potential of teaching programmable automation and other technologies in the context of the humanistic and social considerations that are part of a broad-based education designed to meet the needs of both the individual and society. WPI is especially notable in this respect. One of the goals of the "WPI Plan" is to produce "technological humanists." Two formal internal mechanisms instituted under the plan are the "Humanities Sufficiency" and "Interactive Qualifying Project" requirements. The first is designed to teach engineers and scientists to make use of modes of thought and judgment different from those employed in their own disciplines and to engage their interest in the humanities by allowing them to explore a single topic in-depth and from various angles. The second requirement is a project that involves the interaction between society and technology and focuses on how technological solutions and problems affect human needs and values. BYU and a number of the other schools investigated also stress broad-based studies that encourage individual students to develop the personal, cultural, philosophical, and social perspectives that increase their capacity to function both as professionals and as people in society.

That role of providing a technical education in the context of a general education is one that industry is neither expected to perform nor equipped to perform. It is, however, a role over which more and more industrialists have expressed concern. A statement made by the president of Texas Instruments may stand as an example of industry's concern:

> Competent persons should be educated broadly enough so that they have the foundation on which to begin their real education, which begins after they leave school. Students need to understand the world they are living in and how we got where we are so they will be equipped to understand the effect of the choices they make later in life. Industry needs business leaders and managers who know the nature of the businesses they will manage and the society they will serve.

That concern is not for "leaders and managers" alone; it extends to all future employees who function as part of a technical team. While a number of industries, like IBM and Texas Instruments, and semi-industrial organizations like JPL, have done a great deal to aid educational institutions, a number of recent studies point to the erosion of the educational sector's capacity to provide basic, technical, and humanistic education that truly prepares students to be productive workers and members of society. Industry support, alone cannot solve the problem; but an ongoing, reasonable dialogue between industry and education can help.

Industrial Programs

Union Training. In union shops, the capacity of the in-plant training programs provided by management often builds on the capacity of the apprenticeship training programs to provide core trade skills. While too few union-sponsored or operated programs were studied in-depth to provide the basis for assessing the capacity of apprentice and journeyman training as a whole, some points can be noted. One is that the union-sponsored or operated training in the two programs covered is similar to the technical training observed in the educational institutions in that it stresses core trade skills as a required foundation for programmable automation skills. While the industrial electrician apprenticeship program at Henry Ford Community College includes the study of programmable controllers and electronic controls at the end of the apprentice program, the Los Angeles IBEW Electrical Training Trust reserves programmable controller skills training for journeyman classes. The decision to teach programmable automation at the apprentice or journeyman level is dependent on a number of factors -- including local industrial demand for such skills -- but the major point here is not whether programmable automation is taught to apprentices or journeymen but that, in both cases, 3 to 4 years of fundamental-trade-skill training precedes programmable automation training. While the union training observed is not as broadly based as the education provided in nonunion technician programs in colleges (that is, it does not include general educational requirements) it is more oriented to the individual than in-plant skills training. The apprentice and journeyman training observed focuses on building the complete range of skills required to perform as a journeyman in a specific trade, whereas in-plant training focuses on the skills and knowledge required to perform a specific job and, in most instances, is built on the assumption that the student is a skilled tradesperson with a flexible range of core trade skills.[48]

In-Plant Training. The major strengths of the in-plant training programs examined are the following: 1) they are, in most situations observed, efficient since they are focused on specific applications and delivered to students who are well grounded in both plant procedures and core trade skills; 2) their effectiveness is increased by the fact that the trainees usually have the opportunity to put their new skills into practice immediately and continously (the skills, in other words, are not lost through atrophy); 3) in many of the situations, there is a well-oiled feedback loop that provides trainers with information on the practical effectiveness of their training; 4) since the trainers are in close contact with system users, programers or maintenance personnel (and since most industrial trainers have previous plant experience in those fields), the training is normally more user-oriented than vendor training; and 5) the trainees themselves are, in most cases, avid learners because they have a highly specific "need to know" the material in order to perform their jobs.

In-plant training is, in general terms, quite obviously limited by the specific needs of the plant. Students learn what they need to know to perform their jobs and no more. This is not a value judgment; it is simply a limitation of scope required for maximum efficiency. In many cases, in-plant training programs create a personal interest on the part of individual trainees who then enroll in college courses (for which the company will usually provide tuition reimbursement) or in after-hour training programs provided free by the company. Some in-plant training programs are also limited by such factors as the unavailability of equipment specifically set aside for training purposes and by understaffed and underbudgeted training departments.

Vendor Training. The basic strengths of vendor training programs examined are the 1) vendors' expertise in the general operations, programming and maintenance requirements of their systems, 2) the attention paid by a number of vendor training departments to utilizing instructional methodologies that attempt to combine flexibility with a systematic approach, 3) a high level of responsiveness to the customers' needs, 4) an increasing emphasis on the need for executive and manager training, and 5) "train-the-trainer" courses that provide in-plant instructors with broad systems knowledge and specific instructional techniques.

The limitations of the vendor training observed are 1) it is, in most cases, not designed to be application oriented, 2) it is quite expensive once the few free training slots usually offered as part of the equipment contract are used up, 3) it is often difficult for customers to schedule training -- especially advanced training delivered after the systems have been installed -- at convenient times. Most vendors included in the case study series offered customer training as part of an often-extensive series of product support services, including field service assistance by specialists who provide unofficial on-the-job training often focused on specific customer applications. However, most producers and users of automated equipment agree that under ordinary circumstances it is not the function of vendor training to do more than provide startup training that gives first time users basic machine or systems knowledge and skills, and advanced maintenance training that helps the customers to maintain the equipment more efficiently. In the case of advanced computer-aided design training, experienced users are trained to make more productive use of the system for a generic application (such as mechanical design, CNC part programming, or printed circuit board design), not, in most instances, to learn highly specific applications.

Needs, Problems, and Trends Common to Educational and Industrial Programmable Automation Instructional Delivery

As illustrated throughout this report, neither the industrial nor the educational sector alone has fully met all the programmable automation training needs, nor has either solved all of the major problems associated with the delivery of such training. Some of those needs and problems are, in fact, common to both sectors. There are, furthermore, some significant trends that apply both to industrial training and to the instruction delivered in educational institutions.

Common Needs

Long- and Short-Term Strategies. While industrial organizations need training strategies that meet both short- and long-term needs to support CAD/CAM implementation and expansion strategies, educational institutions must plan to meet short-term educational needs as best they can considering the difficulties in obtaining equipment and laboratory facilities. At the same time, educational institutions must engage in long-term forecasting and planning consistent with their own educational and research goals and the future industrial need.

Increased Internal Coordination. The need for increased coordination between design and production departments in industries that have either developed or plan to develop a common CAD/CAM (or integrated manufacturing) database is paralleled by the need for educational institutions to increase the coordination among departments engaged in interdisciplinary research and/or teaching activities.

Increased Communication. Enhanced communications networks are needed not only within individual schools and plants, but also between industry and education; among companies engaged in producing, implementing, or expanding programmable automation; and among schools offering programmable automation studies.[49] In addition, prospective students and workers need to be informed about the specific programs offered in particular schools and the present and future skill requirements of the workplace.

There are organizations that gather and compile information on programmable automation and other high technology curricula which can be used by students or workers planning further education. What appears to be needed, however, is a national mechanism for tapping the resources of the already existing organizations and gathering information from schools and industries that may not yet be included in the numerous studies and unofficial networking done by existing organizations. As important as gathering information on curricula, training methodologies, research, equipment needs, local problems, and local solutions is a mechanism for publicizing that information to teachers, prospective students, and workers who may not even know of the existence of the already established information organizations. A well publicized national communications network would enable students to make informed choices of schools that meet their individual needs. It could also make curricular materials from a variety of sources available to schools and industrial training departments. The list of possibilities could go on ad infinitum. What seems clear, however, is that the Federal Government is one of the few entities that has the resources and the potential communications network to provide such a service.

Exchange of Expertise Between Education and Industry. The curriculum-development and teaching expertise of instructors in colleges and universities can be of help to industrial trainers facing the initation or increase of in-plant classroom/laboratory training due to programmable automation. Similiarly, colleges and universities can benefit from simulated or actual industrial projects for their students.

Top Level Organizational or Institutional Support and Self-Motivated Action by Instructors. Well planned and executed training-and-education requires support by corporate management or school administrators. Apart from that top-level support, the need for individual instructors in educational institutions who take action by developing curricula, making industrial contacts, and keeping themselves at the state-of-the-art is paralleled by the need in industry for training directors or managers who can convince top management of the need for training to keep pace with CAD/CAM expansion.

Flexibility. Both industry and education need the flexibility to incorporate the new training and education needs into traditional practices and procedures. This may, in some instances, require restructuring of curricula in educational institutions and restructuring of training practices (or instituting new training procedures) in industry.

Jointly Sponsored Industry-Education Programs. Joint programs with industry can significantly increase the capacities of educational institutions to conduct programmable automation education and research programs. While many industries have difficulties freeing equipment or laboratory facilities for student use, others that have been able to do so (e.g., JPL, Singer Librascope, and Emhart) have seen a return on their investment that takes a variety of forms -- from free coursework for company engineers, to aid in industrial projects, to company-specific training of potential or current employees. Some far-seeing company representatives also recognize that by building the capacities of the schools, they are bettering their future chances of hiring well educated employees, and some believe that colleges can save companies training dollars by delivering in-plant training. In most cases, the companies would first have to train the college instructors in their procedures and practices, but industry supporters of contracts with colleges for training maintain that it would be less expensive than company-operated training and that it has the added advantage of aiding industry and academia at the same time.

Common Problems

Lack of Adequate Resources. While the lack of adequate funding, equipment, and laboratory facilities is most notable in the education sector, this problem has also been observed in some vendor and user firms. A significant implication is that those industries having difficulties filling their own needs for equipment, instructors, and facilities are hardly in a position to aid schools looking to industry for equipment. The national crisis in education that has been receiving increasing attention in the media and in numerous official reports appears to be paralleled by the less publicized problem of the low-priority status of training in many industrial organizations. Nevertheless, as the successfully operated industry-education programs illustrate, resources (including the equipment and laboratories in industry and the instructional expertise of educators) can be shared, and Federal, State, and local government agencies can help to facilitate that sharing of resources by providing additional funds and by creating linkages -- as was done on both the State and local levels in the instance of California's Coordinated Funding Project.

Resistance to Change. A number of industry and education representatives have pointed out that many individuals in their own organizations and institutions exhibit a strong resistance to the sweeping changes that may be brought about by programmable automation and other emerging technologies. Not only individuals, but entire organizations show this resistance. While overresponding in an ill-considered fashion is certainly a danger, the traditional gradualism of change in education and training makes a failure to respond in time a more prevalent problem.

Keeping up with the Constantly Changing State-of-the-Art. While many educators have difficulties keeping up with industrial advances in technology and while postsecondary educational institutions as a whole face the extreme difficulty in keeping their laboratory equipment up-to-date, industrial trainers (especially in vendor firms) face parallel difficulties in keeping up with software updates and new releases of both software and hardware. The solution to this problem, as to so many others, is increased resources allotted to educational institutions and industrial training organizations so they can hire more trainers, curriculum specialists and, in the case of educational institutions, more faculty to reduce the strain on the departments as a whole. The "solution," however, is a problem in itself, since education and training resources appear to be scant in a number of schools and industries.

Finding and Keeping Instructors. The problem here is obvious. High school, college, and university instructors who have developed programmable automation expertise are attractive to industry and must be dedicated teachers to pass up the lure of higher industrial salaries. Many potential instructors never set foot in academia for the same reason. ndustrial training departments, especially in vendor firms, have similar problems.

Common Trends

Cross Training and/or Interdisciplinary Studies Plus the Systems Approach for Engineers and Managers. Technical colleges and high schools stress the need for interdisciplinary coursework, especially in robotics and other computer-aided manufacturing studies. This parallels the cross training of mechanics, electronics technicians, and other technician-level workers and maintenance personnel in plants where union provisions do not preclude workers from crossing occupational trade boundaries in the work performed. In some union plants which do have such provisions (where, for example, electrical maintenance personnel do not perform mechanical maintenance functions) in-plant training courses often provide familiarity with those portions of the system not directly the responsibility of the individual mechanical or electrical maintenance workers. The systems approach to computer-integrated manufacturing studies offered by some engineering schools is, perhaps, paralleled by in-plant training in networking CAD/CAM systems and by systems overview couses for managers.

Education and Training in Technical Management. The trend toward providing overview courses for managers is also paralleled by new master's degree programs in technical management for engineering personnel. Some of the universities studied combine MBA coursework with graduate level engineering courses (often focusing directly on programmable automation) to produce trained technical managers.

Increased Attention to the Relationship between Education-and-Training and Productivity. This trend is related to the growing emphasis on life-long learning. A large number of in-plant trainers and managers interviewed equated ongoing in-plant training with increased plant productivity. One of the major selling points of vendor training is that adequate instruction is required to enable workers to make the most productive use of CAD equipment and to keep CAM equipment operating at peak efficiencey. Trainers in the union operated training program studied were, perhaps, the most explicit of all. Said one: "the only thing we have to sell are our skills and knowledge -- these must be pertinent if we are to continue to function as productive workers in a changing field."[50] Educators concerned with the personal productivity of their students after they leave school emphasize the necessity of continuing the learning process after formal education is completed. The WPI program, for example, is specifically structured to produce students who are capable of "learning to learn for themselves in a professionally competitive atmosphere." Acccording to one WPI representative, "the net result is that, if the program succeeds in meeting its goals with individual students, "those students who become practioners have an infinite half-life as engineers, instead of the currently predicted 1-year half-life."

FOOTNOTES

1. A degree option is a series of courses focusing on a particular subject area within a traditional degree program. Electronics students at one community college studied, for example, may take an optional series of courses in "Automation/Robotics." Students who complete the option receive an associates' degree in electronics and a certificate in robotics.

2. In one of the companies studied, apprenticeship training is delivered by the firm. In that instance, the training provided by the company takes on the nature of the union sponsored training.

3. See footnote 16 for the distinction between generic-applications training and company specific applications training.

4. Half of the firms investigated were unionized; half were not.

5. "Program," here, refers to the total number of programmable automation training courses delivered at a single company or plant. In most cases, the programmable automation training program consists of a variety of different courses serving the job-related needs of a variety of workers.

6. At the Westinghouse Defense Center, workers receive apprenticeship training in core trade skills in the plant. One Defense Center machinist program, for example, builds from courses in conventional machining skills to courses in the operation of computer-aided machines. That program combines a focus on building the individual's core trade skills with a company focus on productivity, operating efficiency, and product quality.

7. CAM, in this report, includes the use of robots, programmable controllers, computer numerical control machines, and other computer-aided equipment used in the manufacturing process.

8. Diagnostic programming helps electrical maintenance personnel to locate faults in the electrical/electronic systems. Many electrical maintenance personnel learn to isolate faulty modules and troubleshoot them by writing diagnostic programs on the machine-code language level and some learn to write high-level language programs which are executed using the proprietary software programmed in by the machine vendor.

9. While CAD user training does not require a great deal of manual dexterity, the manual design and drafting skills that are normally prerequisites for CAD training do involve manual precision.

10. The aircraft manufacturer has company-specific definitions for CAM and CAD/CAM. CAM is defined as the use of computers to control the machines that fabricate and build the product. CAD/CAM is the use of computers throughout the design and production cycle; it includes product analysis and design as well as the communication of that data in computer sensible form for direct use by manufacturing.

11. The term "training pocket" is used by the company to describe formal or informal (OJT) training delivered by unofficial trainers in a specific department to others in that department.

12. The commercial aircraft division and the computer services division are two of the many operating divisions in the firm's corporate structure.

13. All electrical maintenance personnel receive either robotics or programmable controller training. Other maintenance workers receive training as their jobs require it.

14. Defense Center representatives estimate that the goals are at least halfway met and will be met completely within 3 years.

15. The training of eight welders during the applications development stage of the Defense Center's first welding robot resulted in a number of suggestions made by the welders which were incorporated into the applications development. For example, suggestions made by welders observing the engineers' attempts to solve a recurrent problem with the tips of the welding torch helped the engineers to locate the source of the problem. Once the source was located, the engineers were able to rewrite the software to solve the problem. The engineers also followed the welders' advice to rewrite some ambiguous wording in the computer control's "help file" (a series of user-friendly prompts that guide a welder/operator who is unsure of the operational sequence).

16. This is a general rule, and like all general rules, it has its exceptions. Most of the vendor firms studied provide application-oriented training on specific occasions, usually when a large amount of training is delivered to a single customer (usually a large firm) and that customer specifically requests application-oriented training. In addition, some vendor firms that specialize in designing customized systems deliver customized training more frequently than vendors that sell standardized systems or machines, and many vendors offer training in generic applications. The distinction between application-oriented in-plant training and the instruction in generic applications delivered in some vendor courses can best be described by the following example: whereas a trainee in a vendor course may learn to use a CAD system to design a printed circuit board (a generic application), in-plant training may focus on specific configurations using specific types of materials (such as particular weight and thickness of copper wire). In addition, each firm has company specific design procedures that are taught in in-plant training courses. One firm, for example, requires all of the wires on its boards to make 45 degree-angle turns, so designers in that firm must learn to construct a 90 degree angle using two 45 degree angles.

17. The applications laboratory was an unplanned by-product of the in-plant training program. The applications lab succeeded so well in practice that the GMC Corporate Education and Training Department is now encouraging other plants to establish technical training facilities incorporating training laboratories that can also be used for applications research and development. In the case of the "S" Truck plant, the applications lab has been used to test out ideas for mounting weld guns on the welding robots, designing welding hoses specifically adapted to the robots' movements, and numerous other peripherals and attachments specifically suited to the plant's needs.

18. See footnote 15 for an example of the impact of worker involvement during applications development.

19. National Electrical Contractors' Association

20. The two computer-aided design firms now have (or have the potential to address) broad markets, ranging from heavy manufacturing companies to electronics firms to companies specializing in architectural planning and facilities layout. CMI's machine tools and robots are used in a variety of manufacturing companies. Automatix serves a similar market to CMI's Robot Division's, except that Automatix has a greater focus on customers requiring specially configured robot and vision systems (i.e., Automatix works with the customers' engineers to develop the systems configurations, software, and peripherals precisely suited to the customers' applications needs, rather than basing its sales on a large volume of standard systems for which the customers develop their own applications peripherals or software programming). GCA's Semiconductor Division serves a narrower market than the other vendors: GCA's customers are producers of integrated circuits.

21. CADAM Inc., as noted previously, is a subsidiary of the Lockheed-California Corporation. Although the software firm was not incorporated until January 1, 1982, the history of the CADAM product goes back to 1967, when the original CADAM software was developed by Lockheed-California engineers. By 1975, Lockheed was selling CADAM software to users outside of the corporation, and in 1979, IBM adopted CADAM as its internal CAD/CAM software. IBM and Lockheed entered into a contractual arrangement in 1976 whereby IBM would market and distribute CADAM software to IBM hardware customers. Between 1976 and 1981, a large percentage of CADAM system software was licensed through IBM to customers who bought IBM-hardware/CADAM-software packages. When it incorporated, CADAM, Inc., continued the contractual relationship with IBM begun by its parent company, licensing the bulk of its software through IBM.

22. While the vendor firms' customers are, in actuality, the corporate executives of the user firms, in terms of training, that vendor-customer relationship filters down to the relationship between the vendor's instructors and the user firms' technical and shopfloor personnel. In terms of training, then, "customer satisfaction" translates into meeting the students' instructional needs.

23. See Section II, p. 100-103.

24. Westinghouse may have significantly reduced this communications problem by assigning training responsibilities to operating department managers and shopfloor supervisors. The GM "S" Truck plant also has a negligible communications problem as long as the training does not expand beyond the Maintenance Department.

25. Precise numbers or percentages of customers who had established in-plant training programs were not available.

26. Project SEED instructors employ a highly interactive teaching methodology -- a nonlecture, question and answer format -- that keeps the students interested and involved. Furthermore, the teachers are taught techniques for dealing with incorrect answers in a constructive and nonthreatening manner.

27. In Michigan, all local school districts are part of an intermediate district. The majority of the functions performed by the intermediate districts are paid for by state school aid, by bonding authority, or by taxing authority.

28. Every 5 years, the vocational education staff in the school district surveys county employers to ascertain current and anticipated labor needs and the degree of skill required for entry-level jobs. Other surveys assess the vocational interests of both students and their parents. All of the survey data is then used as the basis for curriculum planning and development in the centers and local high schools. Local industrial advisory committees established for each occupational program also help to keep the instruction in line with current industrial needs by reviewing course content and recommending necessary modifications. Each of the centers operates a job placement service. The placement offices contact employers and arrange interviews for graduating students.

29. Apart from administering occupational programs, ROP has the following functions: student needs assessments (diagnosis of educational level and appraisal of occupational potential), labor market surveys, guidance and counseling, placement assistance, and job development.

30. The Oakland Intermediate District Centers also provide occupational and skills upgrade training to adults. In the evenings, the centers are operated by the Adult Education Department.

31. The Glendale Private Industry Council was formed under Title VII of the Comprehensive Employment and Training Act (CETA). Title VII, the Private Sector Initiative Program, was aimed at giving business and industry a major role in designing and implementing employment and training programs tailored to local private sector needs. The successor to CETA, the Jobs Training Partnership Act, retains the private industry councils created under CETA and expands their responsibilities and authority.

The Jet Propulsion Laboratory is a private, nonprofit research and development laboratory which is a principal NASA contractor but which also has research and development contracts with the U.S. Department of Energy, the Department of Defense, the National Institutes of Health, some local agencies, and some private industries.

32. CAD-lab assistants perform such duties as operating photoplotters and (after some work experience) digitizing of drawings.

33. The magnet high school concept has been in existence for well over a decad Other school systems, such as Washington, D.C.'s, also employ it.

34. The course modifications and additions were those suggested by an ad hoc industrial advisory committee made up of representatives of firms that produce robots, firms that produce automated machines that interface with robots, and Robotics International of the Society of Manufacturing Engineers.

35. The apprenticeship program, like other occupational and educational programs at HFCC, is supported by a combination of State revenues, city taxes, and Federal funds.

36. Programs focusing on programmable automation were not developed for the pilot run because 1) HFCC had difficulties in obtaining proper space and equipment, and 2) information gathered in labor market surveys did not indicate that definite employment prospects would exist in that skill area in the near future.

37. HFCC has also been chosen as the site of the Ford-UAW National Retraining Center. The Center will house administrative and research staffs which will locate job opportunity information and organize retraining courses at HFCC and other colleges across the country.

38. Because the number of TI participants has not always corresponded to the enrollment requirements for Eastfield classes, open slots in the TI classes have, on occasion, been filled by other students in the Electronic Design Program.

39. Of the first 12 participants, 5 were hired by JPL, 2 were employed by Singer, and 3 were placed in other organizations.

40. The Accreditation Board for Engineering and Technology (ABET) also recognizes the necessity for engineers and technologists to work together as a team on industrial projects. According to ABET representatives, it is for that reason ABET has accredited over 700 associate and bachelor degree technology programs in colleges and universities.

41. BYU and WPI also emphasize "life-long learning skills," although the methods employed by each school to encourage life-long learning are different. The trend toward the development of such skills and the stress placed on the need for life-long learning is discussed on pp. 138-9.

42. According to Texas Instruments representatives, the cost is $5 to $6 million for all the equipment needed in the process.

43. While the selection of students by industry could be carried to a dangerous extreme, it should be noted that the two college programs mentioned are relatively small programs specifically created to serve the hiring and training needs of particular industries. Furthermore, one of the long-range goals of the participating industries in both cases is to build the colleges' capacities to operate independent programs. Students in the high school program were selected by school representatives.

44. Other schools in the area do offer programs which provide exposure to a number of different models of robots.

45. See footnote 46.

46. Because only the Texas Instruments program was covered at Texas A&M, that university is not discussed in the general comments on university programs. For a description of Texas A&M's Industrial Automation Laboratory, see A Response to Advancing Technologies, American Society for Engineering Education, pp. 66-68.

47. Accreditation Board for Engineering and Technology.

48. One observed exception to this is the Westinghouse Defense Center training for automated materials handling, which does not require previous training in a conventional manufacturing trade.

49. Numerous professional societies -- such as the Society for Manufacturing Engineers and Computer-Aided Manufacturing International -- enable professional engineers to exchange information on state-of-the-art techniques and problems. In addition, engineering education associations and vocational training societies spread information among educators and trainers. Conferences such as that held by BYU for universities engaged in programmable automation teaching and research also help. As widespread as these organizations may be, however, they are still limited in that not all trainers and educators can afford the time or receive the funding to attend meetings.

50. A large number of the members of the particular IBEW local studied worked on a temporary or permanent basis for small electrical contractors, many of whom could not afford to provide formal in-house training.

APPENDIX

Case Study Format
Industrial Training Program

Background Statement on Company

- Type of operation, description of products
- Nature of establishment (entire company, division, subsidiary, plant, branch) numbers and size of branch plants or offices
- Number of years establishment in place
- Size of establishment (gross sales, first 2 quarters 1982; entire year, 1981; size of workforce; size of workforce engaged in manufacturing products) composition of workforce
- Labor intensive nature of establishement (labor intensive or capital intensive?)
- Extent of programmable automation (percent of manufacturing equipment using microprocessors and/or programmable controllers; type of programmable equipment used on production floor; length of time programmable equipment in place; extent of integration of programmable equipment; future plans for installation of programmable equipment)
- Occupational categories of workers affected by programmable automation: shop floor staff who assemble, handle, or load material; shop floor staff who operate equipment; repair and maintenance staff; production engineers and programers; design engineers and programers; supervisors (managers) of shop floor personnel; executives

Description of specific training or retraining programs, activities, and outcomes to date

Brief Description of Range of Training Programs Sponsored by Firm

Employee Training programs (including management and shop-floor workers, on programmable and nonprogrammable equipment):

OJT; apprenticeship programs; short-term (1-3 days) on specific equipment or job; general information seminars, special-topic courses (e.g., electronics, programming)

Occupational groups served

Customer Training Programs

Firm's Philosophy of Training

- How does training fit into organizational activities?
- To whom does training staff report? (Personnel, Production, other)
- What input does training staff have to organizational goals?
- Does firm have a full-time training department or staff? size?
  If not, does firm have a training firm/consultant on retainer or otherwise involved .
- Coordination of training department with production departments.
- Training manager's statement of training philosophy.
- Is career counseling offerred to employees?
  Links, if any, between training department and personnel department.
  How is training related to career ladders, internal transfers, and mobility?

Employee training programs (programmable equipment)

- Program goals
- Cost of program (total cost, cost per trainee)
  - personnel costs
  - equipment costs
  - books and materials
  - one-time costs (itemize); fixed costs
- Participation of educational institution or consulting firm

  at what stage was the institution or consulting firm involved?

  what was its role?
  - training provider
  - developed curriculum
  - task analysis
  - other consultation

  institutional, State or local government funds used?

  contribution of government expertise, facilities, etc.?

  description of cooperative agreements between firm, educational institution (and union, if applicable)

  description of responsibilities and activities of educational institution or consulting firms

- Trainee selection criteria
    - prerequisites for participating in training program
    - occupational categories
- Training staff
    - number of trainers
    - background
    - extra training required to teach course (who delivered trainer's training -- training firm, educational institution, producer firm, others within company?)
- Training facility
- Equipment
- Class size
- Length of training
- Curriculum outline
- Evaluation of trainees (written tests, manual skills tests, other)
- Follow-up (formal, informal)
- Evaluation of program by trainees (formal, informal)
- Evaluation of curriculum and staff by management
- Results (how many trainees successfully completed)
- Problems and solutions

Customer Training:

- Contractual arrangements between vendor and customer (e.g., does the price of the equipment include one or more training slots? Is training a separate price item? Maximum number of customer's employees trained with sale of system.
- Average length of training (taking into account variations of systems):
    - basic
    - advanced
    - other
- Training staff
    - total size of customer training staff
    - number of instuctors per class
    - background of instructors
- Class size
- Occupational categories of trainees

- Training facility
    - separate customer training facility
    - vendor's plant(s)
    - customer's plant(s)
    - description of training facility (space, equipment, location)
- Curriculum outline (average basics class)
    - percent lecture, percent demonstration, percent hands-on; homework required?
- Curriculum outline (average advanced class)
    - percent lecture, percent demonstration, percent hands on, homework required?
- Description of training delivered by special arrangement with customer
    - ex. instructor hired by the day to deliver training at customer plant
    - ex. vendor firm trains trainers from customer plant, provides customer firm with video-tape library
    - ex. outside training or consulting firm involved
- Training delivery (general questions)
- Computer-aided learning, instructor delivered, mix?
- Audio-visual equipt used?
- Standardization of training vs. training tailor-designed to customer firm's needs (does vendor see one or the other of these as a priority -- if not, how is best mix achieved?)
- Attention to human factors (how does vendor handle trainees, who question their own ability to operate programmable equipment or are concerned about the effect the equipment may have on their job security; do trainers attempt to serve as a communicative link between top management and employees to, for instance, explain the effects of the new equipment on the total factory environment, manager-worker relations?)
- Evaluation of trainees
    - written tests
    - performance tests
    - certification
    - other
- Follow up -- does vendor firm provide follow-up assistance (telephone calls, visits, hot-line, etc.)?
- Evaluation of training program by trainees
    - is there a formal evaluation?
    - are trainees available for evaluation at time of interview?
- Results
    - increase in productivity, operating efficiency and/or product quality in customer firm (over previous 6 months)?
    - increased job satisfaction (trainees)?

learning curve (how long does it take for increase in productivity to take place)?

- Problems and solutions

Description of Relationship with Union

- Is customer plant unionized?
  which union(s)?
- At what stage was union informed of intention to install programmable equipment?
- Extent of union's involvement in training arrangements and delivery
- Were unionized workers trained?
- Who does installation, maintenance, and programming?
  union workers? nonunion technicians, programers? vendor employees or subcontractors?

Evaluation of present and future capacities to address training needs related to programmable automation in manufacturing

In-plant Employee Training

Evaluation by plant management

- Has productivity, product quality, and/or operating efficiency increased?
- Was the work flow disrupted by the program?
- Did the program meet its goals, company goals?
- Other

Evaluation by union local

- Did the training meet the workers' needs, union's needs?
- Did workers feel work flow unnecessarily disrupted?
- Was program beneficial in terms of increased skills and worker satisfaction?

Evaluation by researcher

Customer Training

Evaluation by customer firm

- Was training conducted in a timely and efficient manner?
- Did training meet firm's needs?

c Did problems with equipment or trainees arise subsequent to training?
   were the problems easily solved?
   did vendor firm assist in solving difficult problems?
   were trainees prepared to handle everyday problems with equipment?

Evaluation by Union (if applicable) or individual workers.

Suggested Alternative Roles Firm Might Play in Providing Training

Vendor firm's suggestions

Customer firm's suggestions

Union's suggestions

Researcher's suggestions